

Process regime variability across growth faults in the Paleogene Lower Wilcox Guadalupe Delta, South Texas Gulf Coast



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ABSTRACT

The Wilcox Group in Texas is a 3000 m thick unit of clastic sediments deposited along the Gulf of Mexico coast during early Paleogene. This study integrates core facies analysis with subsurface well-log correlation to document the sedimentology and stratigraphy of the Lower Wilcox Guadalupe Delta. Core descriptions indicate a transition from wave- and tidally-influenced to wave-dominated deposition. Upward-coarsening facies successions contain current ripples, organic matter, low trace fossil abundance and low diversity, which suggest deposition in a fluvial prodelta to delta front environment. Heterolithic stratification with lenticular, wavy and flaser bedding indicate tidal influence. Pervasively bioturbated sandy mudstones and muddy sandstones with *Cruziana* ichnofacies and structureless sandstones with *Ophiomorpha* record deposition in wave-influenced deltas. Tidal channels truncate delta front deposits and display gradational upward-fining facies successions with basal lags and sandy tabular cross-beds passing into heterolithic tidal flats and biologically homogenized mudstones.

Growth faults within the lower Wilcox control expanded thickness of sedimentary units (up to 4 times) on the downdip sides of faults. Increased local accommodation due to fault subsidence favors a stronger wave regime on the outer shelf due to unrestricted fetch and water depth. As the shoreline advances during deltaic progradation, successively more sediment is deposited in the downthrown depocenters and reworked along shore by wave processes, resulting in a thick sedimentary unit characterized by repeated stacking of shoreface sequences. Thick and laterally continuous clean sandstone successions in the downthrown compartments represent attractive hydrocarbon reservoirs. As a consequence of the wave dominance and increased accommodation, thick (tens of meters) sandstone-bodies with increased homogeneity and vertical permeability within the stacked shoreface successions are created.

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1. Introduction

Siliciclastic shelf margins in unstable settings, where subsidence is a response to sediment load are characterized by thicker accumulation of costal facies than those that occur in stable settings (Winker et al., 1983). The progradation of deltaic successions in these settings is controlled by syndimentary faults and the interplay between subsidence and sediment supply.

The Wilcox Group is a 3000 m thick unit of clastic sediments deposited in a rapidly subsiding, unstable basin along the northern margin of the Gulf of Mexico during late Paleocene–early Eocene (Galloway et al., 2000) over an interval of about 12 million years (Fig. 1). The regional stratigraphy of the Wilcox Group was interpreted from well log correlations and seismic interpretations at a large scale (Fischer and McGowen, 1967; Bebout et al., 1982; Winker et al., 1983; Hargis, 1986; Galloway

et al., 2000; Hargis, 2009). Depositional environments have been inferred based on log pattern interpretation and sandstone isopach maps (Fischer and McGowen, 1967; Galloway et al., 2000). Gross changes in lithology and depositional environments have provided the basis for subdividing the Wilcox Group into major regressive–transgressive cycles of sedimentation (Figs. 1, 2). There are relatively few detailed studies of depositional systems based on core and outcrop interpretations (Winker et al., 1983; Breyer and McCabe, 1986; May and Stonecipher, 1990; Davidoff and Yancey, 1993; Yancey et al., 2010). Although the effects of subsidence rate on the vertical successions are readily apparent, the extent to which faults control depositional environments is less clear (Winker, 1982). There are only few studies that consider growth fault control on depositional systems and shoreline progradation (Brown et al., 2004; Olariu et al., 2013; Olariu and Olariu, 2015).

The depositional axes of the Wilcox Group in Texas shifted from northeast to southwest with time (Galloway, 1989). The Lower and Middle Wilcox have depocenters that correspond to the Rockdale Delta system in the Houston Embayment (Fischer and McGowen,

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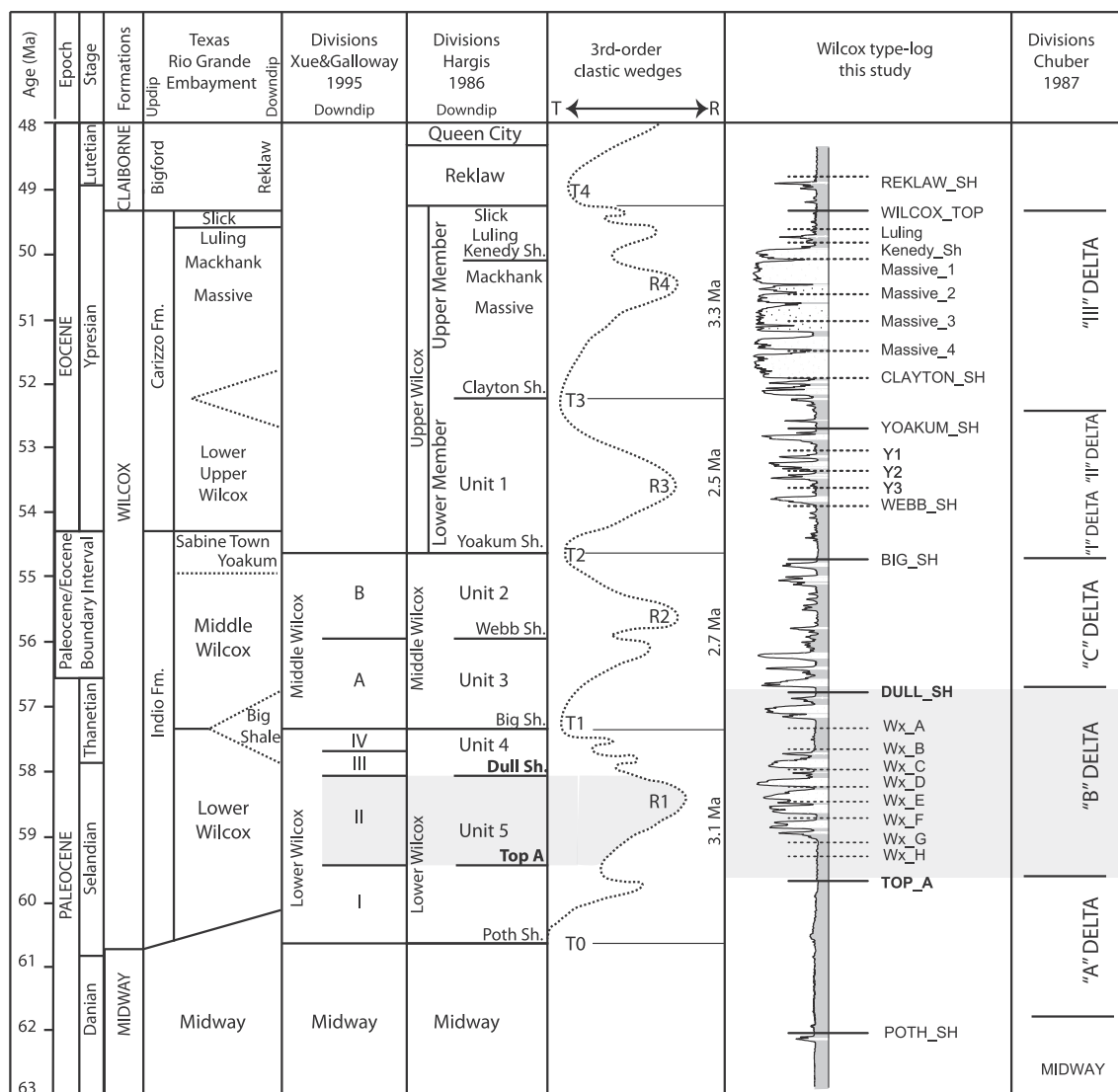


Fig. 1. Correlation chart showing lithostratigraphic divisions for the Texas Wilcox Group (modified from Crabaugh, 2001). Gross changes in lithology and depositional environments provide the basis for subdividing the Wilcox Group into major regressive–transgressive cycles.

1967), whereas the Upper Wilcox was primarily deposited by the Rosita Delta system in the Rio Grande Embayment to the southwest (Edwards, 1981) (Fig. 2). The Rockdale Delta system comprises 7 deltas (Fig. 2) and is up to 1500 m thick (Fischer and McGowen, 1967). The lower Wilcox sequence is bounded by regional flooding surfaces associated with the Big Shale at the top and Poth Shale at the bottom (Xue and Galloway, 1993) and is subdivided into three major intervals called “deltas”– delta A (between Big Shale and Dull Shale), delta B (from Dull shale to top A) and delta C (from top A to Poth Shale) (Chuber, 1987; Hargis, 2009) (Fig. 1). Since the entire lower Wilcox Group lasted about 3 Myr (Crabaugh, 2001), this results in about 1 Myr for each “delta”.

The southernmost Guadalupe delta is one of the largest and thickest deltas of the Rockdale system (Fig. 2). Within the Guadalupe delta, Fischer and McGowen (1967) identified B and C deltas (Fig. 2) and based on the lobate/elongate geometry of the sandstone bodies in the subsurface interpreted them as fluvial dominated.

The objectives of this study are to (1) recognize and describe depositional environments, facies architecture and detail the stratigraphy of the lower Wilcox Guadalupe B delta using cores and well log data, (2) understand the variability of dominant processes on the shelf at a fourth-order scale (cca. 100 Ky), and (3) describe the interaction

between the delta depocenters and growth-faults which is the first step to understand sediment delivery and fairway location at the basin scale.

2. Geologic setting

Wilcox sediments overlie marine mudstones of the Midway Group that were deposited on a broad continental shelf which extended across south Texas during the early Paleocene (Galloway et al., 2000). The top of the Wilcox Group is marked by the Reklaw shale which represents a marine transgression of the Reklaw Sea during middle Eocene (Fig. 1). The Wilcox crops out in a 1000 km long and 15–30 km wide belt, located 150 km to 300 km inland from the present day coastline (Fig. 2). The lower Wilcox deposition records the first major Cenozoic influx of clastic sediment into the west and central Gulf Coast basin (Xue and Galloway, 1993; Galloway et al., 2000) draining Laramide Rocky Mountains and the Cordilleran Arc (Blum and Pecha, 2014; Fulthorpe et al., 2014; Mackey et al., 2012). Regional uplift and tectonism within the interior of western North America provided a great amount (500–1000 m/My) of siliciclastic sediment into the Gulf of Mexico basin during the Paleogene (Galloway and Williams, 1991; Crabaugh, 2001; Mackey et al., 2012). Basin margin

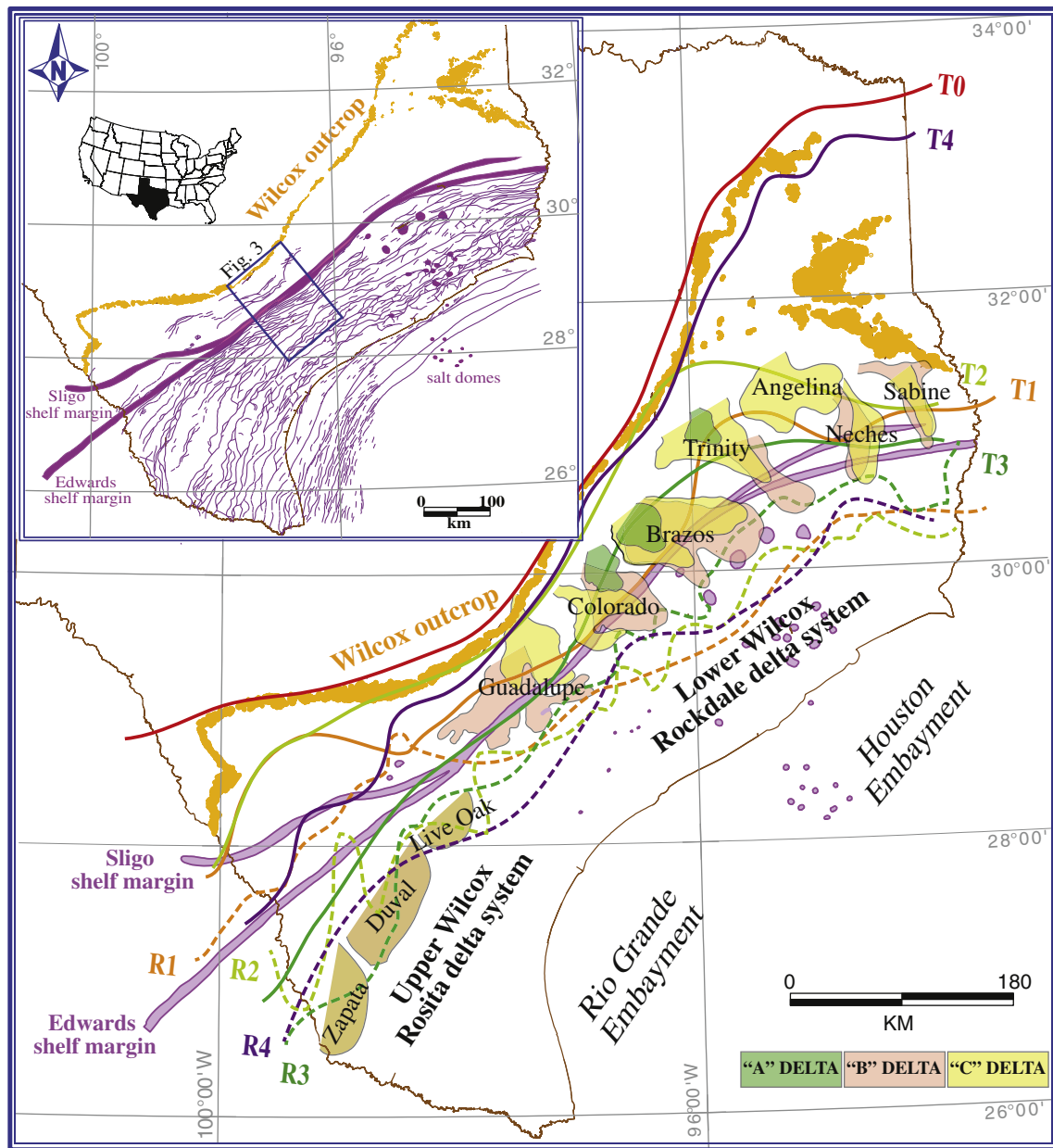


Fig. 2. Paleogeographic maps depicting paleoshoreline positions in the Wilcox Group and distribution of principal deltas (modified from Edwards, 1981 and Fischer and McGowen, 1967). Maximum regressive (R) and transgressive (T) shoreline positions (from Crabough, 2001) delineate the main clastic wedges in the Wilcox Group of Texas. Upper Wilcox Rosita and Lower Wilcox Rockdale delta systems and their components deltas are indicated. Cretaceous carbonate shelf margins (Sligo and Edwards) and salt domes are shown in purple. Closely spaced normal faults (purple lines) can be traced over considerable distances (tens of km) along strike. The structural strike (NE–SW) is parallel to the present day coastline. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

subsidence was largely controlled by differential sediment loading on thick unstable shale. Growth faulting above the Cretaceous carbonate shelf margins caused great expansion (growth ratio as great as 10, although more typically about 2) of clastic sediments within the onshore Wilcox group (Winker and Edwards, 1983). The sedimentary wedge thickens basinward from 60–300 m near the outcrop to about 3000 m in the subsurface over a distance of about 160 km (Fischer and McGowen, 1967; Bebout et al., 1982). Syn-sedimentary and post-sedimentary normal faults can be traced over considerable distances (tens of km) along strike. Structural strike is parallel to the depositional strike and to the coastline and regional dip is toward the coast (Fig. 2). These growth faults separate elongate subbasins (few km wide) which as the system prograded succeeded one another in a southeastward direction

(Fig. 3). Hanging-wall rollover anticlines developed as a result of listric fault geometry and differential loading of deltaic sediments above ductile shale (Winker et al., 1983; Olariu and Olariu, 2015).

3. Data and methodology

Subsurface control consisted of about 700 wire-line logs (SP) supplemented by 182 m of core from 3 wells (Fig. 3). The study area of about 3000 km² is bounded basinward by the downdip limit of well control. Structural relationships were characterized on well-log cross-sections (Figs. 4, 5) and seismic profiles (Fig. 7). The stratigraphic and depositional characteristics of the Lower Wilcox Group were examined in detail in cores.

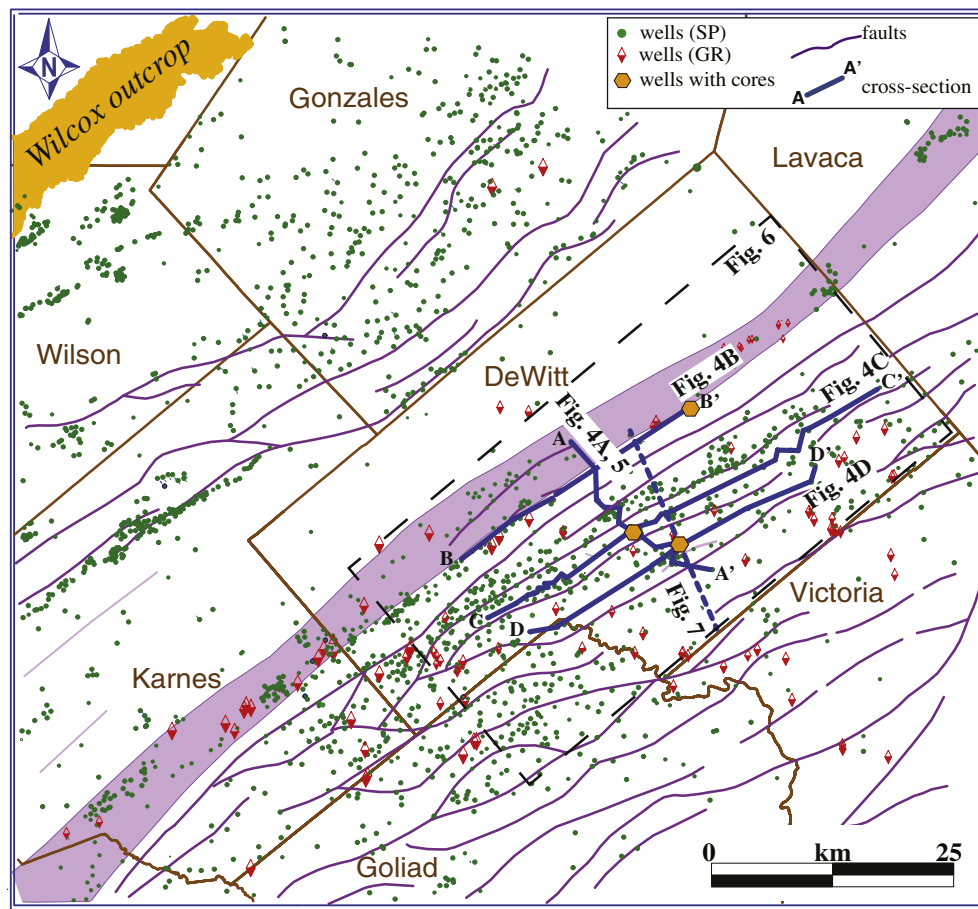


Fig. 3. Location map of the study area. Subsurface control consisted of about 700 well logs (SP) supplemented by cores from 3 wells. Stratigraphic dip and strike-cross-sections and seismic line are indicated in blue. Closely spaced normal faults (purple) run NE–SW parallel to the depositional strike and to the coastline. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Lithologies such as sandstone and shale were interpreted primarily from electric log patterns through log normalization and cutoff log values for each lithology. Spontaneous potential (SP) curves were normalized to make the maximum and minimum deflections equal in all wells by rescaling the curves. Normalization was done according to a type of SP curve (with -20 MV for sandstone–shale cutoff). Logs were checked to verify that cutoff values adequately separate sandstone from shale. Sandstone values between -80 and -20 MV were used to build sandstone percent maps to outline sandstone body geometry and to interpret depositional environments. In growth-faulted settings, sandstone percentage maps are more useful to interpret depositional environments and locate axes of sediment input as they remove the differential subsidence and emphasize depositional control on lithofacies distribution (Galloway et al., 1982; Winker and Edwards, 1983). The computation of sandstone thickness between surfaces of interest was achieved with Petra™ software and involved the creation of a grid for the study area using the least squares method.

Subsurface well-log correlation was achieved using the genetic sequence approach of Galloway (1989) because the muddy intervals formed during high-frequency marine transgressions are readily recognizable and laterally traceable on SP logs. Since the duration of deposition for the Guadalupe B Delta is estimated to have lasted about 1 Myr and is interpreted to contain 10 regressive–transgressive cycles (parasequences), this results in about 100 kyr for each cycle. Mapping of the fourth-order sedimentary cycles was attained through recognition of individual regressive deltaic complexes (upward-coarsening log motifs) and thin intervals of coastline transgression (upward-fining units) delimited by flooding surfaces (high values on SP logs) marked by

muddy sediments of subregional extent (Fig. 4) within each well log. Wave-dominated deltas in which wave and storm action rework the sediment have a blocky log motif (Figs. 4D, 5) (see also Bhattacharya, 1988; Bhattacharya and Walker, 1991) which can be differentiated from the serrated funnel-shaped log motif of upward-coarsening units of wave and tide-influenced deltas (Figs. 4C, 5). There is a gradual upward-coarsening from heterolithic intervals of the prodelta to the sandier delta front deposits of the wave and tidally-influenced deltas (Figs. 4C, 5), whereas the sandstones in wave-dominated deltas have sharp contacts with the mudstones of the prodelta (Figs. 4D, 5). Serrated, blocky and upward-fining log motifs represent heterolithic coastal plains and sandy fluvial and tidal channels (Xue and Galloway, 1995). Flooding surfaces were traced laterally to the nearby wells and correlated in 3-D. Seismic and well-log data were combined within Landmark's Decision Space Geosciences to map stratigraphic surfaces and faults. Core descriptions have been integrated with well-log analysis in order to test lateral continuity of sedimentary facies and coeval depositional systems (Fig. 5).

4. Results

4.1. Structural deformation

The stratigraphy of the Wilcox Group is complicated by syn-sedimentary normal faults which are identified in the subsurface on seismic profiles (Fig. 8) or in well logs (Figs. 4, 6) by missing or expansion of section or abrupt changes in log character over small distances across faults. The examined seismic line (see Fig. 3 for location) is

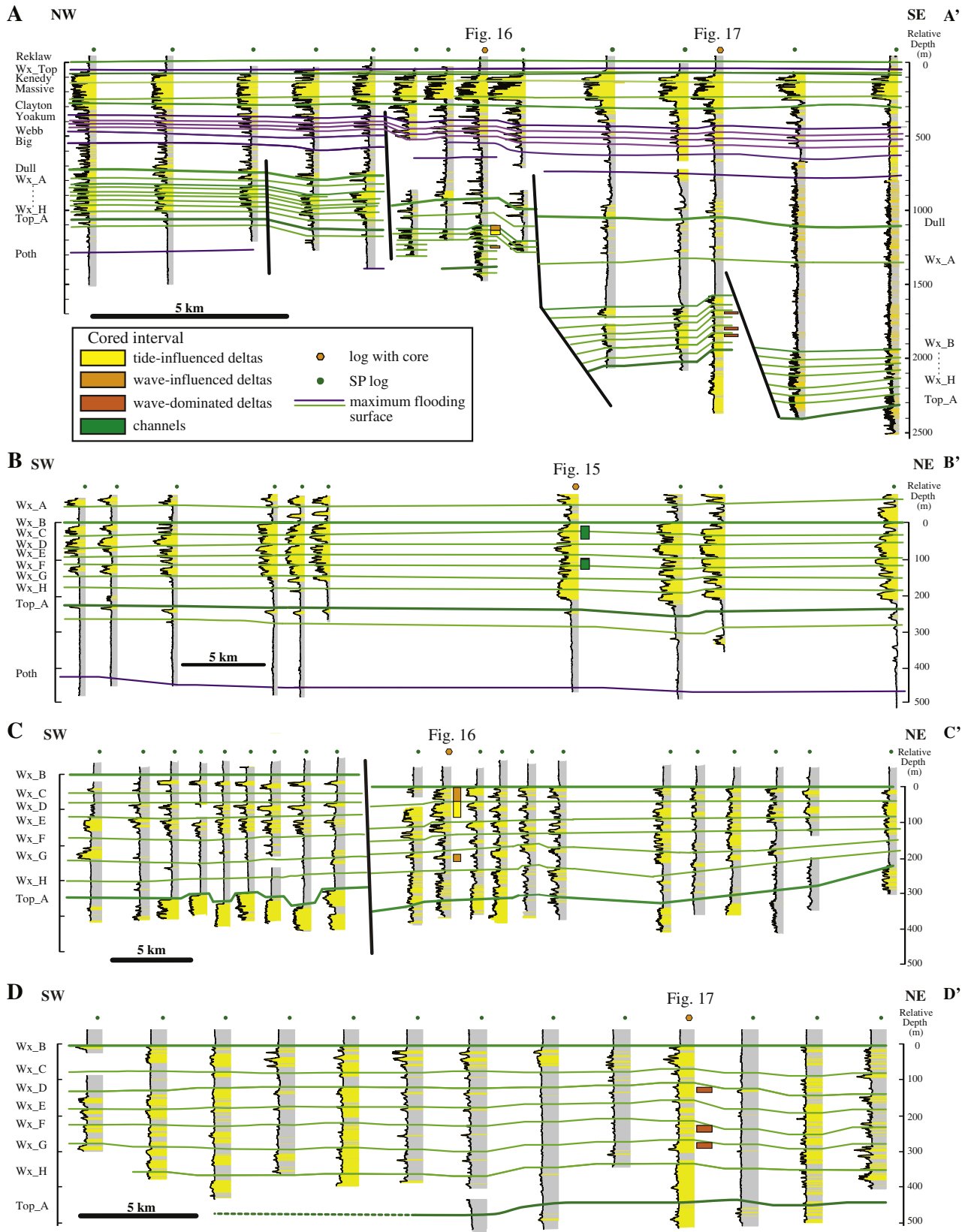


Fig. 4. Stratigraphic cross-sections through the Wilcox Group. Spontaneous potential (SP) curves are used for correlation (logs with core are indicated by orange dots). A. Stratigraphic dip section. The stratigraphy of the Wilcox Group is affected by normal faults (datum is the top of the Wilcox). Maximum flooding surfaces (green, purple) separate 4th order cycles (for location see Fig. 3). Stratigraphic strike sections (datum used is the top of Wilcox B) in B. proximal (serrated, blocky and upward-fining log motifs represent heterolithic coastal plains and sandy fluvial and tidal channels) C. medial (serrated, funnel-shaped and upward-coarsening log motifs of wave and tide-influenced deltas) D. distal settings (upward-coarsening blocky log motifs of wave-dominated deltas). There is a gradual upward-coarsening from heterolithic intervals of the prodelta to the sandier delta front deposits of the wave and tide-influenced deltas, whereas the sandstones in wave-dominated deltas have sharp contacts with the muds of the prodelta. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

characterized by continuous, subparallel reflections in the upper part (upper and middle Wilcox) which become inclined and increasingly off-set by faults in the lower part (lower Wilcox). Several major faults and associated rollover anticlines on the downthrown side are the dominant structures with a few antithetic and synthetic faults (Fig. 8). All faults in the study area exhibit syn-sedimentary growth, with thickened or additional sedimentary units on their downthrown sides (Figs. 6, 8). Major faults have broadly basinward-concave, northeast–southwest strike trends and basinward dips toward the southeast (Figs. 3, 7). The dip of these faults decreases with depth from nearly vertical to less than 30°. Offsets become progressively less up-section, suggesting that rates of fault movement decreased over time (Fig. 8). Upper horizons show displacements of about 100 m, whereas lower ones can be displaced with more than 600 m (Figs. 4A, 8).

Within the Lower Wilcox section proximal faults have displacements of about 300 m, whereas distal ones can reach more than 600 m. Individual 4th-order cycles (cca. 100 kyr) expand up to 4 times across growth faults (Fig. 6). Expansion ratios are expressed as the downthrown thickness divided by upthrown thickness. Hanging-wall rollover anticlines develop in distal settings and are associated with great fault displacements and section expansion (Figs. 6, 8). Stratal thickening occurs on the downthrown sides adjacent to faults and sediments thin away from faults in a dip direction (Figs. 6, 8).

4.2. Sandstone maps

Eight fourth-order sedimentary cycles (Wilcox A – youngest to Wilcox H – oldest) with thicknesses between 64 m and 122 m have been identified within the Guadalupe B Delta (about 1000 m thick).

Sandstone maps depict depocenters and depositional environments within fourth-order cycles (Fig. 7). The maximum sandstone thickness within each deltaic complex ranges from 36 m to 70 m with an average of about 50 m. The sandstone body geometry is affected by a series of closely spaced (2 to 4 km) normal faults (dotted lines in Fig. 7)

immediately (about 10 km) downdip of the Cretaceous carbonate shelf margin; the maps show elongate dip-oriented geometries (Fig. 7). The fault spacing becomes wider (5–10 km) in distal areas, as the faults (continuous lines) become associated with rollover anticlines and sandstone bodies build strike-elongate belts (Fig. 7). Although the transition from a dip-elongate to a strike elongate pattern is not quite obvious in all maps (therefore it was difficult to obtain quantitative estimates of shoreline migration) apparently this transition occurs over small distances (few kilometers) indicating that shoreline remains roughly in the same position over time (short excursions – advance and retreat – of the shoreline between successive sequences).

4.3. Facies description and interpretation

Cores from three wells were described and 23 distinct lithofacies identified, for the interpretation of depositional environments (Table 1). The cores are located in adjacent sub-basins separated by growth faults within a distance of about 15 km along dip (Fig. 3). Core logs record grain size, physical and biological sedimentary structures. The degree of bioturbation is described by the bioturbation index (BI) of Taylor and Goldring (1993); BI ranges from 0 (no bioturbation) to 6 (bioturbation has blurred primary structures). The cored intervals correspond to various fourth-order sedimentary cycles (Wilcox A through Wilcox H); with only Wilcox F present in all 3 cores. The cored intervals at the proximal location total about 60 m and comprise Wilcox B, C, E and F. The medial core records deposition of about 75 m in Wilcox B, C, and F. The distal core is about 47 m thick and comprises three depositional cycles Wilcox D, F and G.

Six facies associations that correspond to distinct depositional environments have been identified. Individual facies described and interpreted below is not necessarily diagnostic for one depositional environment, but the association of facies and their relative abundance is.

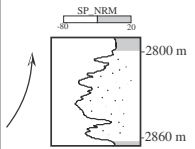
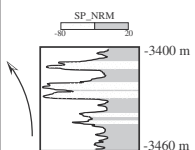
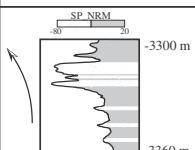
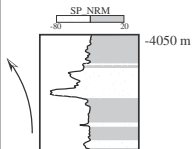
SP log motifs	Description	Interpretation
	ratty, blocky and bell-shaped log motifs (upward-fining units)	heterolithic and coaly coastal plain deposits and sandy fluvial and tidal channels
	serrated funnel-shaped log motifs (upward-coarsening units)	fluvial-dominated, tide-influenced delta - gradual upward-coarsening units from heterolithic intervals (thinly interbedded sandstone and mudstones) of the prodelta to sandy delta front.
	funnel-shaped, locally bell-shaped log motifs (upward-coarsening units)	fluvial-dominated, wave-influenced delta - gradual upward-coarsening units with multiple thin sandstone units with sharp bases in the prodelta.
	blocky log motifs (upward-coarsening units)	wave-dominated delta, tide-influenced - wave and storm action reworks the sediment making it much sandier than other types of deltas; clean, well sorted sandstones have sharp contacts with the mudstone of the prodelta; tidal influence reflected by the heterolithic character of the prodelta.

Fig. 5. Description and interpretation of log facies Spontaneous potential (SP) logs have been normalized and a cut-off value of (–20) was chosen to define sandstone lithology (dotted pattern). Muddy sediments (gray) have high values on SP logs.

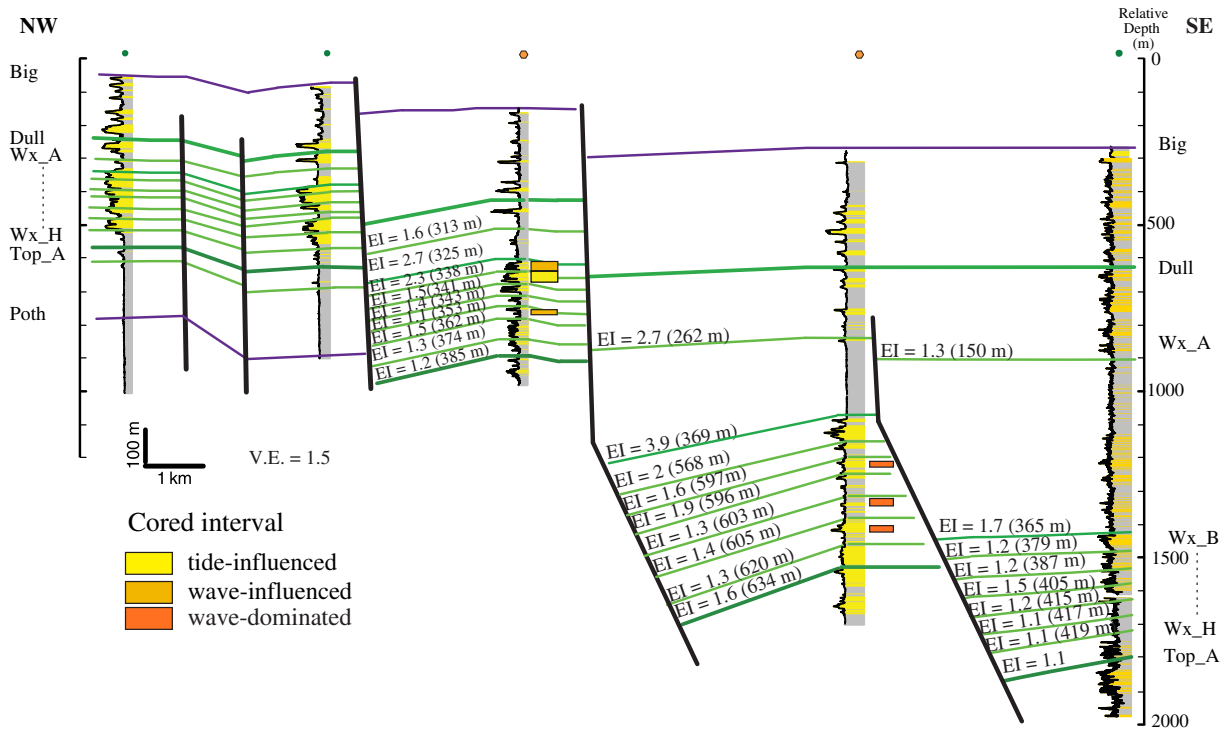


Fig. 6. Structural deformation of the Lower Wilcox Guadalupe B delta. Sketch diagram shows offsets and expansion indexes (EI) for individual forth-order cycles (V. E. = 1.5). This dip cross-section is a simplified version of the cross-section in Fig. 4A (datum is Big Shale).

4.3.1. Facies association 1: fluvial distributary channels

4.3.1.1. Facies 1 – very fine-grained sandstone with mud rip-up clasts. The sandstone is very fine-grained with abundant carbonaceous detritus and carbonized wood fragments (Fig. 9A). Rip-up clasts of plants debris and elongate mud chips show a crude alignment. Pieces of wood several centimeters in length are locally abundant. Flaser bedding formed by carbonaceous and clay drapes occurs locally. There is no evidence of burrowing (BI 0).

Angular to round ripped-up mudstone clasts and large elongate coalified wood fragments are interpreted as lags at the base of channels. The absence of bioturbation suggests an ecologically stressed environment subject to strong currents and/or low or variable salinity conditions. The abundance of plant material indicates a proximal location. Rare flaser bedding indicates local tidal influence.

4.3.1.2. Facies 2 – very fine-grained carbonaceous sandstone. The sandstone has small elongate mud chips and abundant carbonaceous detritus scattered throughout (Fig. 9B). Plant fragments occur locally on bedding planes. There is no evidence of burrowing (BI 0). The abundance of carbonaceous detritus reflects phytodetrital pulses during increased river discharge (floods). The lack of trace fossils and the presence of plant debris and mud rip-up clasts suggest deposition in a distributary channel in a proximal coastal area.

4.3.1.3. Facies 3 – very fine-grained structureless sandstone. Structureless sandstones have sharp bases and are weakly burrowed (BI 0–1) with *Paleophycus* (Fig. 9C). Occasionally faint parallel lamination is accentuated by mud drapes. Mud rip-up clasts and siderite cemented nodules (less than 1 cm in diameter) occur locally. High energy conditions are suggested by mud rip-up clasts. Siderite cementation may indicate fresh water influx. This facies reflects deposition in a channel during high river discharge.

Facies association 1 (FA1) is encountered in younger cycles (Wilcox B and C) in the proximal located core and occurs as an upward-fining successions of fine-grained sandstone that have abrupt, erosional bases overlain by large sideritized mudstone or carbonaceous clasts, wood fragments and plant debris (Fig. 9A, B). The sandstones are largely unburrowed (BI 0–1) (Fig. 15). Bands or concretions of siderite typically occur in mudstones. Abundant organic detritus and carbonized wood fragments and lack of burrowing suggest deposition in distributary channels flowing into bays and lagoons on the upper coastal plain. Occasional mud drapes and flaser bedding indicate some tidal influence in fluvial distributary channels in an upper-to-lower delta plain setting. In tide-influenced and dominated deltas the upper delta plain is above the tidal influence and dominated by fluvial processes (Goodbred and Saito, 2012; Gugliotta et al., 2015).

4.3.2. Facies association 2: tidal distributary channels

4.3.2.1. Facies 4 – poorly sorted fine-grained sandstone. The sandstones have erosive bases, look structureless and are poorly sorted with shells, mud chips and abundant carbonaceous debris (Fig. 10A). Mud rip-up clasts and siderite cemented nodules (about 1 cm in diameter) overlain the erosion (Fig. 10B).

The poorly sorted nature and erosive bases suggest deposition in a channel. Round ripped-up mudstone clasts, shells and siderite nodules are interpreted to be produced as lags in localized areas of channel-floor erosion. Basal lags of tidal channels are mostly shells and mud clasts (Willis, 2005; Olariu et al., 2015).

4.3.2.2. Facies 5 – planar cross-stratified very fine- to fine-grained sandstone. This facies consist predominantly of medium bedded (10–15 cm) planar cross-stratified sandstones (Fig. 10C). Planar cross-stratification is accentuated by carbonaceous (plant material) and mud drapes (Fig. 10C). Locally the very fine-grained sandstone displays planar-lamination alternating with ripple cross-lamination

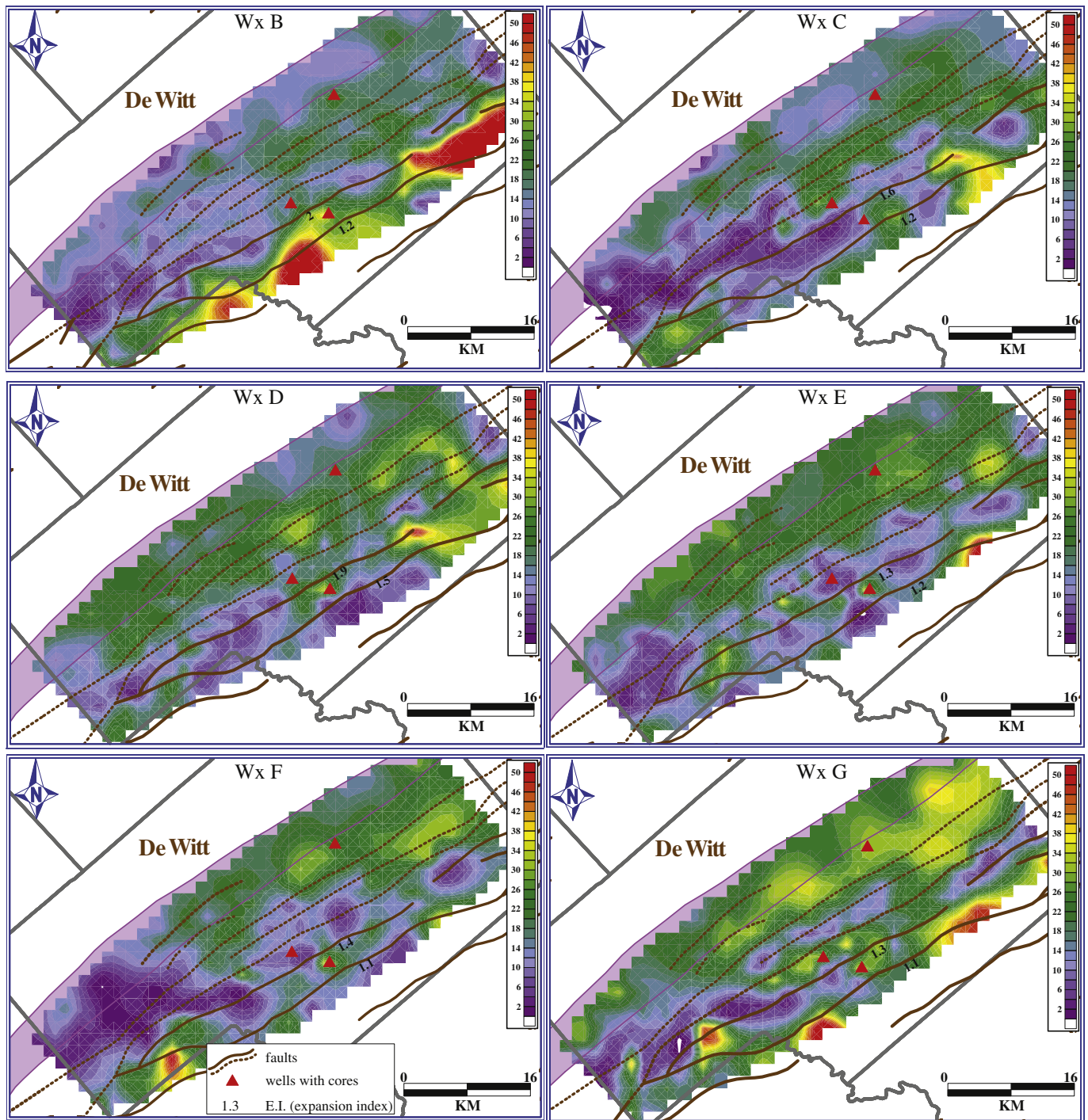


Fig. 7. Sandstone maps for the 4th order cycles Wilcox B to Wilcox G of the Lower Wilcox Guadalupe Delta. The maximum sandstone thickness within each deltaic complex ranges from 36 m to 70 m with an average of about 50 m. The sandstone body geometry is affected by a series of closely spaced (2 to 4 km) normal faults (dotted lines) immediately (about 10 km) downdip of the Cretaceous carbonate shelf margin. The fault spacing becomes wider (5–10 km) in distal areas, as the faults (continuous lines) become associated with rollover anticlines and sandstone bodies build strike-elongate belts.

accentuated by finely comminuted organic detritus. The fine drapes dominated by organic detritus are more common than in FA1. Trace fossils are absent (BI 0).

Sedimentary structures such as planar cross-stratification and current ripple laminae reflect deposition by high-to-low velocity traction currents within channels. Sand layers are interpreted to be deposited during ebb and flood currents, whereas common mud drapes accumulate from suspension during the slack water phase of the tide.

4.3.2.3. Facies 6 — poorly sorted through cross-stratified fine-grained sandstone. This facies is dominated by trough cross-stratification accentuated by common carbonaceous (plant material) and mud drapes (single and double) (Fig. 10D). Some sandstone interbeds are massive with scattered mud chips; some display flaser and wavy bedding (Fig. 10D). Mudstone and carbonaceous interlaminations are common. The intensity and diversity of bioturbation is generally low (BI 1–2) with *Paleophycus*, but increased bioturbation (BI 3–4) occurs locally (Fig. 15). Mud and carbonaceous flasers are typical of tidal influence

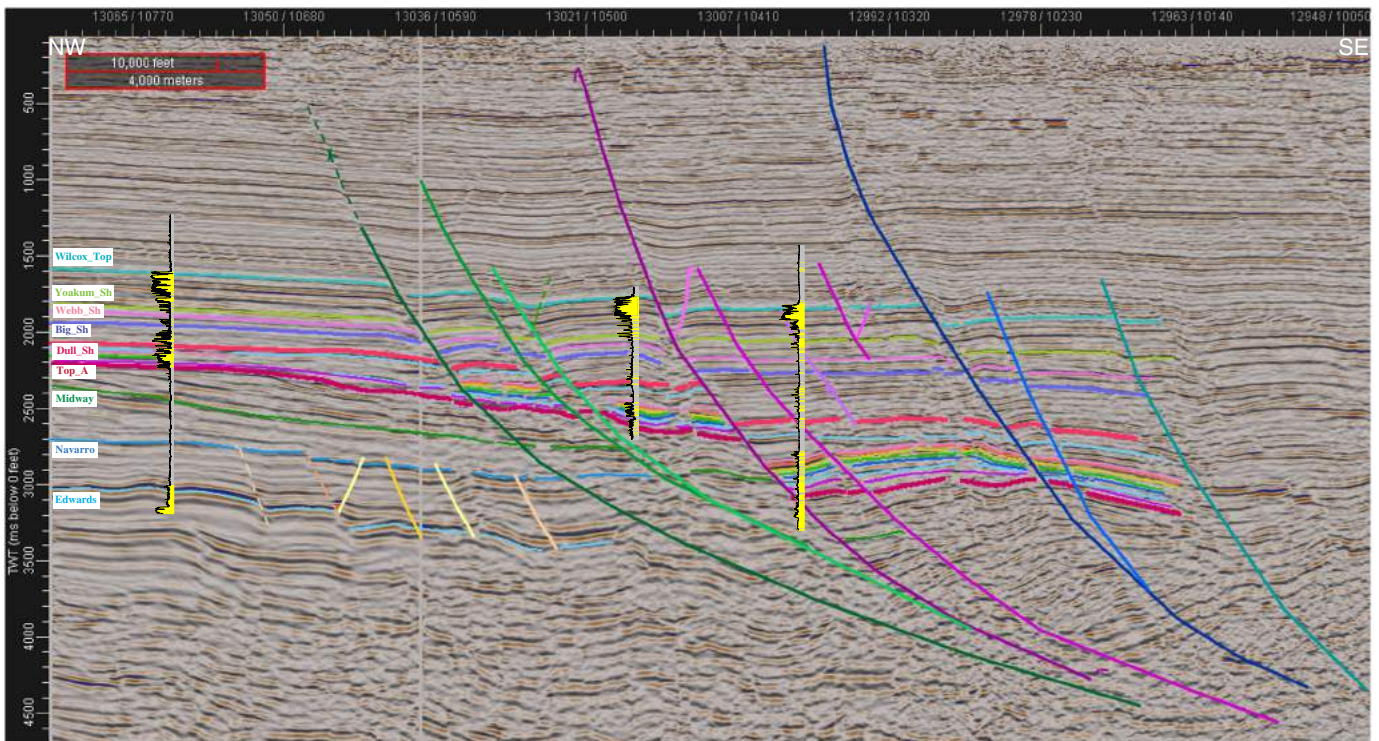


Fig. 8. 2D dip-oriented seismic profile illustrates the relationship between the Cretaceous shelf margin and the Wilcox faults. The examined seismic line (see Fig. 3 for location) is characterized by continuous, subparallel reflections in the upper part (upper and middle Wilcox) which become inclined and increasingly offset by faults in the lower part (lower Wilcox). All faults exhibit syn-sedimentary growth, with thickened or additional sedimentary units on their downthrown sides. Major faults have basinward dips toward the southeast which decrease with depth from nearly vertical to less than 30°. Offsets become progressively less up-section, suggesting that rates of fault movement decreased over time.

within a channel or tidal creek. Although rare (BI 1–4) the presence of burrowing in sandstones indicates marine influence within the channels (Willis, 2005).

This facies association (FA2) is encountered in older cycles (Wilcox E and F) in the proximal located core and records sedimentation in marginal marine environments in tidal distributary channels (Figs. 10, 15). Perhaps the most pervasive, but indirect tidal indicator is the heterolithic nature of the deposits. Bidirectional paleocurrent indicators (e.g., superposition of current ripples with opposite facing directions) although present cannot be fully trusted due to the unoriented nature of the core.

The vertical facies succession within channels starts with an erosion surface at the base overlain by a lag of mud clasts and wood chips that grades upward into tabular cross-stratified and moderately-to-intensely bioturbated sandstone (Fig. 15). The channel lag deposit is locally bioturbated (Fig. 10A). Cross-strata with mud or carbonaceous drapes are common (Fig. 10D). Throughout the channel succession, the sandstone layers decrease in thickness upward and the sediments become progressively finer and more thinly laminated (Fig. 15). The migration of tidal channels across tidal flats generates a typically fining-upward and thinning-upward succession (e.g., Gulf of Papua; Walsh and Nittrouer, 2004). Tidal channel deposits are distinguished from their fluvial counterparts by the abundance and fine scale of mud drapes and extensive bioturbation (Willis, 2005; Willis et al., 1999). Tide-influenced fluvial channels although heterolithic have variable bioturbation (Chen et al., 2015; Olariu et al., 2015).

4.3.3. Facies association 3: tidal flats and lagoons

4.3.3.1. Facies 7 – interbedded very fine-grained sandstone and mudstone. Wavy bedding is the dominant physical sedimentary structure. Thinly interbedded sandstones (less than 1 cm) are current rippled and slightly bioturbated with *Paleophycus* (Fig. 11A). Some of the current ripples

contain thin flasers of shale or carbonaceous debris. The thin mudstones (few mm) are slightly bioturbated (BI 1) with *Planolites* and *Thalassinoides*.

The fine grained nature is indicative of low energy conditions. The thin rippled sandstones represent periods of weak current activity. The thin flasers in the ripple cross-stratification could be the results of tidal current reversals. Sedimentary structures together with a trace fossil assemblage containing both dwelling (*Paleophycus*) and feeding (*Planolites*, *Thalassinoides*) structures suggest deposition on a mixed tidal flat or in shallow protected bay.

4.3.3.2. Facies 8 – intensely bioturbated very fine-grained muddy sandstone. Very fine-grained muddy sandstones display flaser and wavy bedding and are intensely bioturbated (BI 4–5) mostly with *Paleophycus* (Fig. 11B). Abundant carbonaceous debris is present both as laminae and as disseminated matter. Some poorly preserved ripples suggest weak currents on a sandy tidal flat.

4.3.3.3. Facies 9 – gray mudstone with organic matter. This dark gray mudstone is thinly laminated with organic matter on bedding planes (Fig. 11C). Locally thin (millimeter) sand lamination and lenticular ripples (less than 1 cm) are present. The sandstone is very fine-grained. Trace fossils are generally absent except within the thin sandy intervals where *Paleophycus* occur rarely (BI 0–1). The pin-stripe sand lamination indicates that sand was periodically introduced in the environment by weak traction currents which alternated with slackwater deposition of fines on a muddy flat or lagoon.

4.3.3.4. Facies 10 – thoroughly bioturbated sandy mudstone with shells. This facies is poorly sorted with fragments of shells, siderite cemented nodules (less than 1 cm in diameter) and organic matter disseminated throughout (Fig. 11D). The mudstone is pervasively bioturbated (BI 5–6) with *Thalassinoides*, *Planolites* and *Asterosoma*. The fine-grained

Table 1
Main facies associations of the Lower Wilcox in the Guadalupe B Delta.

Facies	Description	Ichnofacies	Interpretation
<i>Facies Association 1: fluvial distributary channels</i>			
(1) very fine-grained sandstone with mud rip-up clasts	Sandstone with abundant organic detritus and carbonized wood fragments (Fig. 9A). Rip-up clasts of plants debris and elongate mud chips show a crude alignment. Flaser bedding formed by organic and clay drapes occurs locally.	BI = 0	Angular to round ripped-up mudstone clasts and large elongate coalified wood fragments are interpreted as lags at the base of channels. The abundance of plant material indicates a proximal location.
(2) very fine-grained carbonaceous sandstone	Sandstone with small elongate mud chips and abundant organic detritus scattered throughout (Fig. 9B). Plant fragments occur locally on bedding planes. There is no evidence of burrowing.	BI = 0	The lack of trace fossils suggests an ecologically stressed environment subject to strong currents and/or low or variable salinity conditions. The presence of plant debris and mud rip-up clasts indicates deposition in a distributary channel in a proximal coastal area.
(3) very fine-grained sandstone	Structureless sandstones have sharp bases and are weakly burrowed (Fig. 9C). Mud rip-up clasts and siderite cemented nodules (less than 1 cm in diameter) occur locally.	BI = 0–1 Pa.	High energy conditions are suggested by mud rip-up clasts. Siderite cementation may indicate fresh water influx. This facies is interpreted as channel infill.
<i>Facies Association 2: tidal distributary channels</i>			
(4) poorly sorted fine-grained sandstone	Erosionally based, structureless, poorly sorted sandstone with shells, mud chips, abundant organic debris and siderite cemented nodules (Fig. 10A, B).	BI = 0	The poorly sorted nature and erosive bases suggest deposition in a channel. Round ripped-up mudstone clasts and shell fragments are interpreted as lags at the base of channels.
(5) planar cross-stratified fine-grained sandstone	Medium bedded (10–15 cm) planar cross-stratified sandstone (Fig. 10C). Locally ripple cross-lamination is accentuated by finely comminuted organic detritus. Trace fossils are absent.	BI = 0	Sedimentary structures such as planar cross-stratification and current ripple laminae reflect deposition by high-to-low velocity traction currents within channels.
(6) poorly sorted through cross-stratified fine-grained sandstone	Trough cross-stratification is accentuated by mud and carbonaceous drapes (Fig. 10D). Some sandstone beds are massive with scattered mud chips.	BI = 1–2 Pa.	Mud and carbonaceous flasers are typical of tidal influence within a channel. Rare burrowing indicates marine influence within the channels.
<i>Facies Association 3: tidal flats and lagoons</i>			
(7) interbedded very fine-grained sandstone and mudstone	Wavy bedding with thinly (mm) interbedded sandstones and mudstones. The sandstone is current rippled with thin flasers of shale or organic debris (Fig. 11A).	BI = 1 Pl., Th., Pa.	The fine-grained nature is indicative of low energy conditions. The thin rippled sandstones represent occasional periods of weak current activity. The thin flasers that drape the ripples could be the results of tidal currents.
(8) intensely bioturbated very fine-grained muddy sandstone	Very fine-grained sandstones with flaser and wavy bedding (Fig. 11B). Abundant organic debris is present both as laminae and as disseminated matter.	BI = 4–5 Pl., Pa.	The fine-grained nature and intensity of bioturbation are indicative of low energy conditions. Remnant ripples suggest weak currents on a sandy tidal flat.
(9) gray mudstone with organic matter	Thinly laminated mudstone with organic matter on bedding planes (Fig. 11C). Locally thin (mm) very fine-grained sandstone lamination and lenticular ripples are present.	BI = 0–1 Pa.	The pin-stripe sand lamination indicates that sand was periodically introduced in the environment by weak traction currents which alternated with slackwater deposition of fines on a muddy flat or lagoon.
(10) thoroughly bioturbated sandy mudstone with shells	Poorly sorted thoroughly bioturbated mudstone with fragments of shells, siderite cemented nodules and organic matter disseminated throughout (Fig. 11D).	BI = 5–6 Pl., Th. As.	The fine-grained nature, presence of shells and organic matter suggest deposition in a marginal marine quiet environment such as a bay fill or lagoon.
<i>Facies Association 4: wave- and tide-influenced deltas</i>			
(11) lenticular bedding in mudstone	The mudstone shows lenticular bedding with isolated current and wave-rippled silt and sand streaks (Fig. 12A, B). Locally the mudstone is siderite cemented in bands less than 1 cm thick.	BI = 0–2 Pl., Th. BI = 0–1 Pa.	The very thin (mm) wave-rippled silt and sand stringers are interpreted as the distal equivalents of storm deposits in an upper offshore to distal prodelta of a tide-influenced delta.
(12) interbedded fine-grained sandstone and mudstone	Thinly (1 cm) interbedded sandstones (Fig. 12C, D) are current and wave-rippled; thin dark mudstone drapes the ripples. Wavy bedding is the dominant physical bedform.	BI = 2–3 Pa. BI = 1–2 Pl., Th.	The fine-grained nature is indicative of low energy conditions. The thin rippled sandstones represent occasional periods of weak current activity in a distal prodelta of a tide-influenced delta.
(13) thoroughly bioturbated muddy sandstone	The sandstone is very fine-grained and biogenically reworked such that only vague wavy parallel laminations are preserved (Fig. 12E).	BI = 5–6 Pl., Th. As.	The burrowing intensity, predominance of deposit feeding behaviors and the sedimentary structures indicate that these sediments are deposited under fair weather conditions in a distal delta front of a wave-influenced delta.
(14) structureless fine-grained sandstone with Ophiomorpha	Sharp-based structureless sandstone with basal-lags of mud rip-up clasts (Fig. 12F). The top of the beds is weakly burrowed.	BI = 1–2 Oph., Pa.	This facies is interpreted to represent amalgamated storm beds in a wave-influenced delta front.
<i>Facies Association 5: wave-dominated deltas</i>			
(15) interbedded very fine-grained sandstone and mudstone	Moderately burrowed very fine-grained sandstones alternate with weakly burrowed mudstones (Fig. 13A, B).	BI = 3–4 Pa. BI = 1–2 Pl., Th.	The thin rippled sandstones represent occasional periods of weak current activity in a distal prodelta of a wave-dominated delta.
(16) thoroughly bioturbated sandy mudstone	Thoroughly bioturbated sandy mudstone (Fig. 13C). Physical sedimentary structures are destroyed by burrowing.	BI = 5–6 Pl., Th. Pa., As. Oph., Te.	The predominance of deposit feeding trace fossils of the <i>Cruziana</i> ichnofacies, the high diversity and burrowing intensity suggest deposition in the proximal prodelta of a wave-dominated environment.
(17) intensely bioturbated fine-grained sandstone	Preserved primary sedimentary structures are dominated by wavy parallel and low angle laminae. Rip-up clasts and organic detritus occur locally (Fig. 13D, E).	BI = 5–6 As., Pl. Pa., Oph. Ro.	Wavy parallel and low angle laminae are interpreted to reflect distal hummocky cross-stratification. These amalgamated storm beds reflect deposition in open marine, distal delta front in a moderately to highly storm-dominated setting.

Table 1 (continued)

Facies	Description	Ichnofacies	Interpretation
(18) <i>deformed fine-grained sandstone</i>	Preserved primary sedimentary structures are dominated by soft sediment deformation such as convolute bedding (Fig. 13F).	BI = 1–2 <i>Pa.</i>	Structureless sandstones are interpreted to reflect sediment liquefaction due to syn-sedimentary deformation in response to rapid deposition associated with storm events in a storm-dominated setting.
(19) <i>low angle cross-stratified fine-grained sandstone</i>	Well-sorted, fine-grained sandstones have sharp bases and display low-angle cross-stratification (Fig. 13G, H). Locally the clean white sandstone looks apparently structureless.	BI = 1 <i>Oph.</i>	Faint low angle lamination is interpreted as hummocky cross-stratification. These sandstones represent storm beds in a wave/storm dominated delta front. Wave action inhibits mud deposition and/or resuspends slack-water deposits.
<i>Facies Association 6: transgressive shoreface</i>			
(20) <i>thoroughly bioturbated sandy mudstone</i>	Sandy mudstone with organic matter disseminated throughout (Fig. 14A). Large <i>Thalassinoides</i> (up to 4 cm in diameter) are filled with very fine-grained structureless sandstone.	BI = 5–6 <i>Pl., Th.</i>	The fine grained nature of the sediment, presence of organic matter, intensity of burrowing and low diversity suggest deposition in a quiet environment such as a lagoon behind a barrier bar.
(21) <i>moderately bioturbated fine-grained sandstone</i>	Structureless fine-grained sandstone with sharp scoured contacts (Fig. 14B). The intensity of bioturbation increases toward the top as the sandstone becomes gradually finer grained.	BI = 4–5 <i>Oph.</i>	The scoured base, fining-upward pattern, and increased bioturbation at the top of the sandstone reflect deposition on a drowning barrier bar as the water deepened during transgression, under wave-storm influence.
(22) <i>thoroughly bioturbated very fine-grained sandstone</i>	Intensely bioturbated sandstone; no physical sedimentary structures are preserved (Fig. 14C).	BI = 5–6 <i>Oph., As.</i>	The finer-grained nature and high intensity of bioturbation suggest deposition in a distal open marine setting under fair-weather conditions.
(23) <i>thoroughly bioturbated fine-grained muddy sandstone</i>	Thoroughly bioturbated fine-grained muddy sandstone with organic matter disseminated throughout (Fig. 14D). No sedimentary structures are preserved.	BI = 5–6 <i>Oph., As. Th.</i>	The intensity of burrowing and relatively low diversity suggests deposition in a low energy environment such as a behind barrier lagoon.

nature, intensity of bioturbation, presence of shells and organic matter suggest deposition in a marginal marine low energy environment such as a bay fill or lagoon.

This facies association (FA3) is dominated by thinly laminated heterolithic stratification which consists of alternation of very fine-grained sandstone and siltstone with mudstone on a centimeter scale (Fig. 11A, B). The thin interbedded sandstones (less than 1 cm) are massive to parallel-laminated, whereas slightly thicker sandstones are both wave- and current-rippled (Fig. 11A, B). The ichnofossils represent a *Cruziana* assemblage with *Planolites* and *Paleophycus*. Unstratified, mottled bioturbated mudstones cap the succession (Fig. 11C). Heterolithic strata of facies association 3 typically overlay the sandy deposits of facies association 2 (tidal distributary channels). The association of FA3 with underlying tidal channels (FA2) and an overall upward-fining pattern (Fig. 15) suggests deposition on tidal flats. Extensive burrowing (Fig. 11D) indicates near normal marine salinity in an area protected

enough to allow biogenic reworking such as tidal creeks or lagoons in an intertidal (most likely) to subtidal environment.

4.3.4. Facies association 4: wave- and tide-influenced deltas

4.3.4.1. Facies 11 – lenticular bedding in mudstone. The relatively thick (decimeter) mudstone shows lenticular bedding with isolated silt and very fine-grained sand streaks (Fig. 12A, B). Thinly laminated (mm) current (unidirectional) and wave-rippled siltstones and sandstones are sharp based and weakly burrowed (BI 0–1) with *Paleophycus*. The mudstone is weakly burrowed (BI 0–2) with *Planolites* (Fig. 12A, B). Locally the mudstone is siderite cemented in bands less than 1 cm thick. The trace fossil assemblage represents horizontal feeding traces of the *Cruziana* ichnofacies.

Sedimentary structures (lenticular bedding with unidirectional current ripples) and low diversity and burrowing intensity reflect



Fig. 9. Representative core samples showing characteristics of facies association 1 – fluvial distributary channels (each core sample is 5 cm wide except in C which is 9 cm wide; see well log in Fig. 4) A. very fine-grained sandstone with carbonaceous detritus and carbonized wood fragments. Rip-up clasts of plants debris and elongate mud chips show a crude alignment. Pieces of wood several centimeters in length are locally abundant. B. Sandstone with mud chips scattered throughout and organic debris as laminae. Plant fragments occur locally on bedding planes. There is no evidence of burrowing. C. Very fine-grained structureless sandstone.

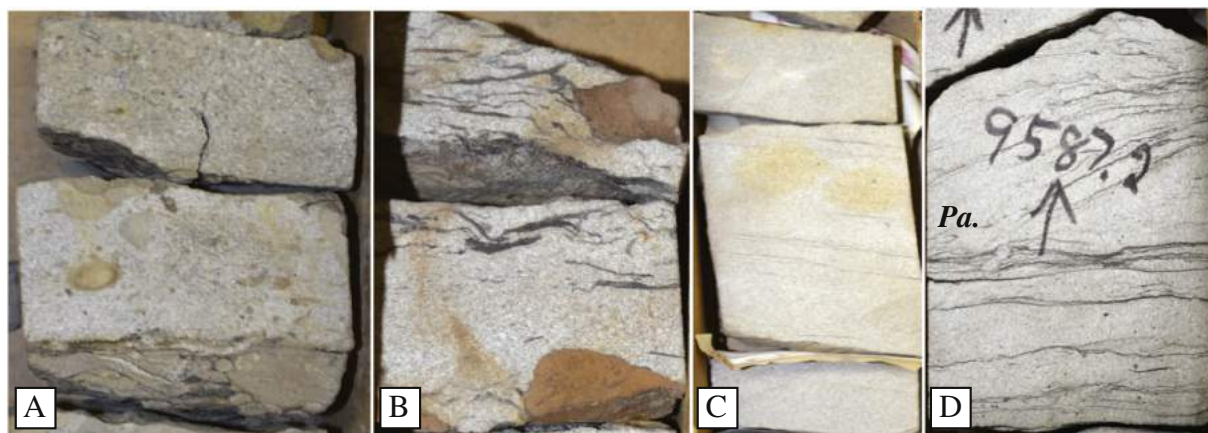


Fig. 10. Representative core samples showing characteristics of facies association 2 – tidal distributary channels (each core sample is 5 cm wide except in D which is 9 cm wide; see well log in Fig. 4). A. Poorly sorted fine-grained sandstone with mud chips and organic matter. B. Poorly sorted fine-grained sandstone with mud and organic clasts and drapes. Mud rip-up clasts and siderite cemented nodules (about 1 cm in diameter) overlain the erosion. C. Planar cross-stratified fine-grained sandstone with mud drapes on foresets. D. Through cross-stratified fine-grained sandstone with double mud drapes. The intensity and diversity of bioturbation is low to moderate (BI 1–2) with *Paleophycus*. Carbonaceous interlaminae are common.

deposition in a proximal prodelta environment. Heterolithic stratification indicates tidal influence. Siderite cementation may indicate fresh water influx. The very thin (mm) wave-rippled silt and sand stringers are interpreted as the distal equivalents of storm deposits.

4.3.4.2. Facies 12 – interbedded very fine-grained sandstone and mudstone (wavy bedding). Wavy bedding is the dominant physical sedimentary structure (Fig. 12C, D) forming decimeter to meter-thick units. Thinly interbedded very fine-grained sandstones (about 1 cm) are current and wave-rippled and slightly (BI 1–2) bioturbated with *Paleophycus* (Fig. 12C, D). Millimeter-thick siderite cemented bands and loading structures occur locally.

The fine-grained nature of this heterolithic wavy-bedded unit is indicative of alternating high and low energy conditions with deposition from traction sedimentation and suspension fallout in a tide-influenced environment. The thin rippled sandstones indicate repeated periods of weak current activity in a prodelta environment. Wave-rippled sandstone beds are interpreted to reflect fairly distal storm events. Thinly laminated mudstones and fine-grained sandstones with discrete burrows formed in a marine environment

where sedimentation rates were low enough and salinities sufficiently high to allow benthic colonization.

4.3.4.3. Facies 13 – thoroughly bioturbated muddy sandstone. The sandstone is very fine-grained and biogenically reworked such that only vague wavy parallel laminations are preserved (Fig. 12E). The intensity of bioturbation is high (BI 5–6) with *Planolites*, *Asterosoma* and *Thalassinoides*. The ichnogenera reflect deposit feeding strategies of the *Cruziana* ichnofacies.

The burrowing intensity, predominance of deposit feeding behaviors and the sedimentary structures indicate that these sediments are deposited under fair weather conditions in a distal delta front of a wave-influenced delta (MacEachern et al., 2005).

4.3.4.4. Facies 14 – structureless fine-grained sandstone with *Ophiomorpha*. The sandstones are sharp-based, occasionally erosive with or without basal lags consisting of mud rip-up clasts (Fig. 12F). The top of the beds are weakly burrowed (BI = 1–2) with *Ophiomorpha* and possibly *Paleophycus*. Occasionally the sandstones display low-angle planar parallel stratification interpreted as hummocky cross-stratification (HCS) (Fig. 12E). The association with muddy sandstones

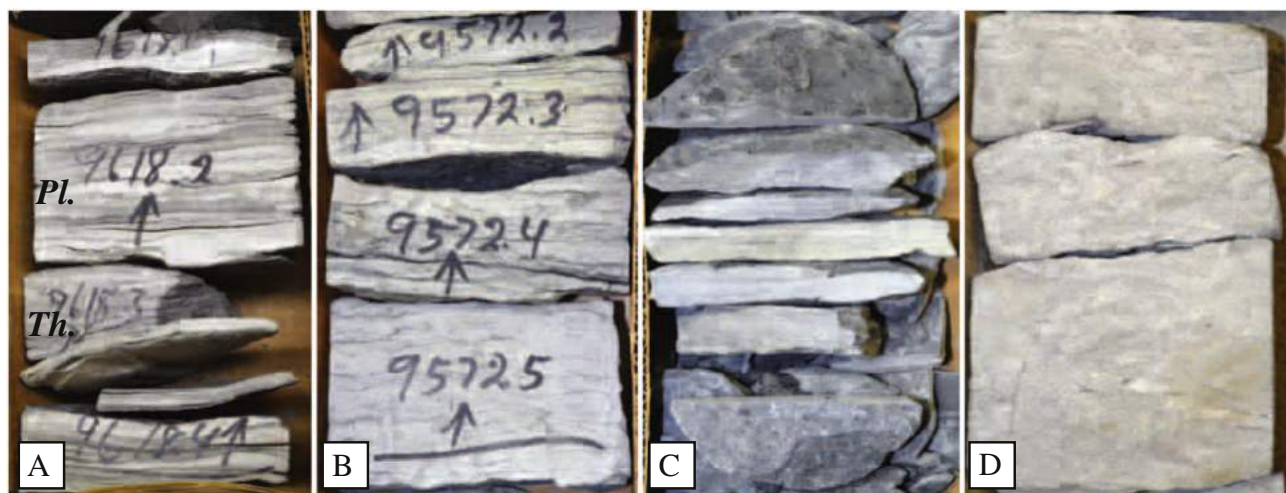


Fig. 11. Representative core samples showing characteristics of facies association 3 – tidal flats and lagoons (each core sample is 9 cm wide except in D which is 5 cm wide; see well log in Fig. 4). A. Interbedded very fine-grained rippled sandstone and mudstone. Thin sandstones (less than 1 cm) are slightly bioturbated with *Paleophycus*. Some of the current ripples contain thin flasers of shale or carbonaceous debris. The thin mudstones (few mm) are slightly bioturbated (BI 1) with *Planolites* and *Thalassinoides*. B. Intensely bioturbated (BI 4–5) very fine-grained sandstone. Abundant carbonaceous debris is present both as laminae and as disseminated matter. C. Thinly laminated dark gray mudstone with organic matter on bedding planes. D. Poorly sorted thoroughly bioturbated muddy sandstone with shell fragments, siderite cemented nodules and organic matter disseminated throughout.

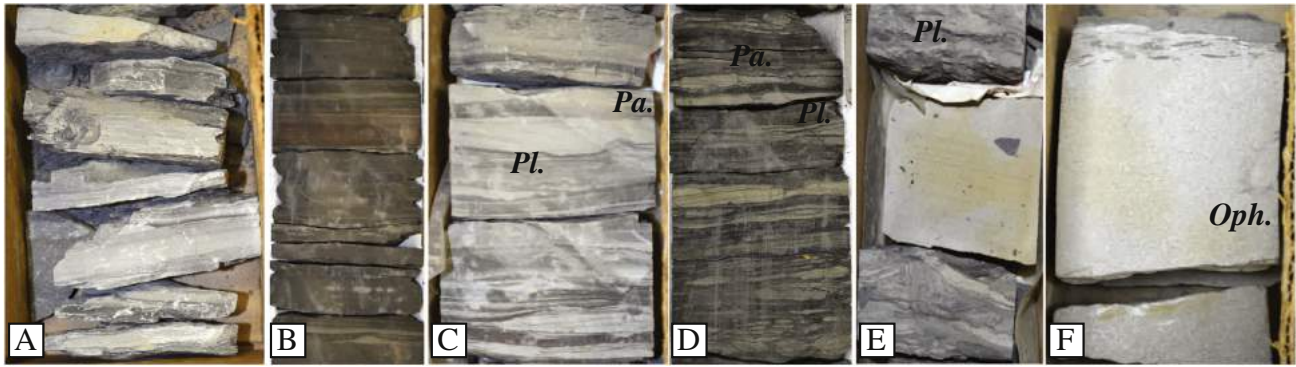


Fig. 12. Representative core samples showing characteristics of facies association 4 – wave- and tide-influenced deltas (each core sample is 5 cm wide; see well log in Fig. 4). A. The mudstone shows lenticular bedding with isolated current and wave-rippled silt and sand streaks. Locally the mudstone is siderite cemented in bands less than 1 cm thick. B. Weakly burrowed mudstone (BI 0–1) with isolated very fine-grained sand streaks (Wilcox F). C. Wavy bedding in very fine-grained sandstone with *Planolites* and *Paleophycus*. C. Wavy bedding in very fine-grained sandstone in distal prodelta. D. Weakly burrowed mudstone (BI 1–2) interbedded with wavy parallel-laminated sandstone (Wilcox D). Locally the mudstone is siderite cemented in bands less than 1 cm thick. E. Thoroughly bioturbated muddy sandstone with *Cruziana* ichnofacies. F. Sharp-based structureless sandstone with basal-lags of mud rip-up clasts. The top of the beds is weakly burrowed with *Ophiomorpha*.

of facies 13 and the presence of HCS make this facies to be interpreted as amalgamated storm beds in a storm wave-influenced delta front.

This facies association (FA4) is encountered in the medial core (Figs. 12, 16). The overall upward-coarsening successions consist of prodelta mudstone showing lenticular bedding with isolated current and wave-rippled sand streaks (Fig. 12A, B) passing upward into distal delta front with wavy bedding in very fine-grained sandstone (Fig. 12C, D) and topped by delta front fine-grained sandstone with *Ophiomorpha* (Fig. 12F). Trace fossils in the prodelta are represented by *Cruziana* ichnofacies with *Planolites* and *Paleophycus* being the most common (Fig. 12B). Low diversity, low density trace fossil suites that contain both dwelling and feeding structures suggest a relatively shallow high energy with variable salinity environment. Tidal reworking occurs during abandonment phase of delta lobes after lobe switching (Plink-Bjorklund, 2012). Fair weather wave reworking is indicated by the rare preservation of wavy parallel laminations in an otherwise thoroughly bioturbated muddy sandstone with *Cruziana* ichnofacies (Fig. 12E). Storm-dominated intervals are characterized by sharply-based structureless sandstones (Fig. 12F) or erosive hummocky cross-stratified sandstones (Fig. 12E) capped by finer bioturbated intervals.

The sediments of facies association 4 in the medial core record deposition in wave- and tidally-influenced prodelta to delta front environments. Wave- and tide-influenced deltaic deposits accumulate on delta-fronts that experience more wave and tide reworking than the fluvial-dominated delta fronts (Bhattacharya and Walker, 1992; Ainsworth et al., 2011). Impoverishment of bioturbation intensities, lower ichnological diversities coupled with current ripples, and siderite cemented bands all may indicate a deltaic environment in the proximity to fluvial discharge.

4.3.5. Facies association 5: wave-dominated deltas

4.3.5.1. Facies 15 – interbedded very fine-grained sandstone and mudstone. Thinly interbedded very fine-grained sandstones (about 1 cm) are current and wave-rippled and slightly (BI 1–2) bioturbated with *Paleophycus* (Fig. 13A, B). The sandstones are locally sigmoidal showing mudstone couples along current ripple foresets (Fig. 13A); wave ripples with muddy interlaminae are also present. Sandstones are commonly sharp based, but locally show scoured basal contacts. Some sharp-based beds contain low-angle planar parallel stratification. Thin dark mudstone (mm-thick) slightly (BI 0–1) (Fig. 13B) to moderately (BI 3–4) bioturbated (Fig. 13A) with *Planolites* and *Thalassinoides* drapes the sandstone.

The fine-grained nature is indicative of low energy conditions and accumulation of sediment at and below fair-weather wave base and

marine bioturbation is typical of a distal prodelta of a wave-influenced or dominated delta. Thin unidirectional rippled sandstones reflect occasional periods of weak current activity. However, some tidal influence is reflected by the presence of mud drapes interpreted to have been deposited from suspension during flow attenuation during tidal cycles. Wave influence is indicated by abundant wave ripples. Low-angle planar parallel stratification is interpreted as hummocky cross-stratification (Dott and Bourgeois, 1982). Low levels of bioturbation within the sandstone suggest an ichnological stressed environment related to heightened sedimentation rates. Wave rippled and thin hummocky cross-stratified sandstone beds are interpreted to reflect fairly distal storm events. Thinly laminated (mm) mudstone with discrete burrows formed where sedimentation rates were low enough and salinities sufficiently high to allow benthic colonization. Wave and storm-dominated deltaic succession (as opposed to nondeltaic shorefaces) are markedly heterolithic even well into the upper parts of the delta fronts (Bann et al., 2008). An alternative interpretation of thinly bedded low angle laminated and rippled fine-grained sandstones is deposition from river floods as hyperpycnal deposits (Mulder et al., 2003). However, some of the key characteristics of hyperpycnal deposits (inverse to normal grading) and typical alternation of sedimentary structures (structureless to parallel laminated to structureless) were not observed.

4.3.5.2. Facies 16 – thoroughly bioturbated sandy mudstone. The sandy mudstone is thoroughly bioturbated (BI 5–6) with *Thalassinoides*, *Planolites*, *Paleophycus*, *Asterosoma*, *Ophiomorpha* and *Teichichnus* (Fig. 13C). The ichnofossils are from *Cruziana* assemblage of deposit feeding organisms. Although most of the physical sedimentary structures are destroyed by burrowing, some sandstone beds with hummocky cross-stratification are preserved.

The predominance of deposit feeding trace fossils, the high diversity and burrowing intensity suggest deposition under fair-weather conditions in open marine environments with low sedimentation rates. Alternation of relatively thick fair-weather suites (FA15) with hummocky cross-stratified sandstones reflects evidence of infrequent storms in the proximal prodelta of a wave-dominated lobe.

4.3.5.3. Facies 17 – moderately to intensely bioturbated fine-grained sandstone. Decimeter-thick fine-grained sandstones are moderately to intensely bioturbated (BI 5–6) with *Planolites*, *Paleophycus*, *Asterosoma*, *Ophiomorpha* and *Rosselia* (Fig. 13D, E). The trace fossil association is indicative of *Cruziana* ichnofacies. Preserved primary sedimentary structures are dominated by wavy parallel and low angle laminae. Rip-up clasts and organic detritus occur locally. The bases of the sandstone beds are erosive truncating the fair weather trace assemblage of

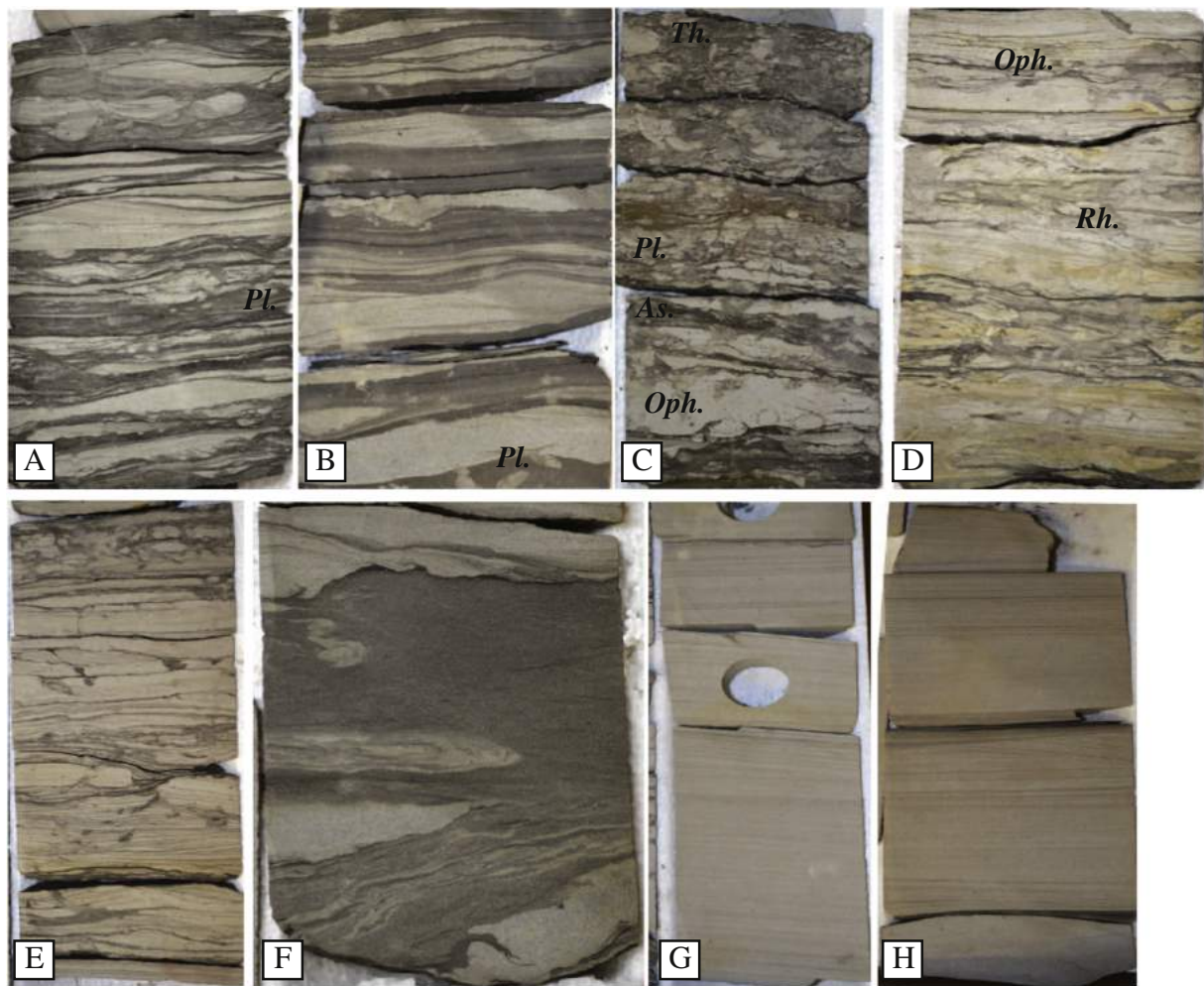


Fig. 13. Representative core samples showing characteristics of facies association 5 – wave-dominated deltas (each core sample is 9 cm wide; see well log in Fig. 4) A. Thinly (about 1 cm) interbedded very fine-grained sandstones are current and wave-rippled and slightly (BI 1–2) bioturbated with *Paleophycus*. Thin dark mudstones (mm) are moderately (BI 3–4) bioturbated with *Planolites* (Wilcox D). B. Mudstone displaying lenticular bedding with isolated current-rippled sand streaks in distal prodelta (Wilcox F). C. Thoroughly bioturbated muddy sandstone (BI 5–6) in proximal prodelta (Wilcox F). D. Alternation of intensely bioturbated fair-weather suites with storm beds in distal delta front (Wilcox D). Preserved primary sedimentary structures are dominated by wavy parallel and low angle laminae. E. Slightly bioturbated amalgamated storm beds with hummocky cross-stratification (Wilcox G). Rip-up clasts and organic detritus occur locally. F. Soft sediment deformation in silty sandstone with organic matter (Wilcox F). G. Well-sorted, decimeter-thick, fine-grained sandstones have sharp bases and display hummocky cross-stratification locally accentuated by organic drapes (Wilcox F). H. storm beds with hummocky cross-stratification (Wilcox G).

facies 16, whereas bioturbation generally obscures the upper contact between the sandstone beds of facies 17 and the fair weather deposit.

Wavy parallel and low angle laminae are interpreted as hummocky cross-stratification reflecting deposition by storm events (Dott and Bourgeois, 1982). The degree of burrowing within the sandstone bed and the thickness of the preserved fair weather deposits (facies 16) are variable and reflect the combined effect of varied storm intensities and frequencies. Carbonaceous detritus reflects storm-induced influxes of terrestrially derived material from nearby distributary mouths. Similar to facies 15, the wavy rippled and low angle laminated sandstone beds of facies 17 might be interpreted as hyperpycnal deposits (Mulder et al., 2003) especially considering the presence of organic matter. However, typical characteristics of hyperpycnal beds (inverse to normal grading, alternation of structureless with parallel laminated sandstones) were not observed. Despite the possibility of linked river-flood with storms these amalgamated event beds are thought to reflect deposition in open marine, distal delta front in a moderately to highly storm-dominated setting.

4.3.5.4. Facies 18 – intensely deformed fine-grained sandstone and mudstone. Preserved primary sedimentary structures are dominated

by soft sediment deformation such as convolute bedding. The fine-grained sandstone is apparently structureless and weakly bioturbated (BI 1–2) with *Paleophycus* (Fig. 13F). Distorted sandstone is incorporated within a weakly burrowed mudstone.

During storm events severe scouring of the shoreface occur coupled with soft sediment deformation, dewatering and possible liquefaction of rapidly deposited sediment (Bann et al., 2008). Intensely deformed sandstones associated with mudstone indicate rapid deposition and substrate liquefaction during large storms.

4.3.5.5. Facies 19 – low-angle cross-stratified fine-grained sandstone. Well-sorted, decimeter thick fine-grained sandstones have sharp bases and display parallel and low-angle cross-stratification (Figs. 13G, H). Slightly convex upwards laminae are preserved in the sandstones (Fig. 13H). Locally the clean white sandstone looks apparently massive. The trace fossil diversity is low with the dominant ichnogenera being *Ophiomorpha* (BI 1).

Amalgamated beds of low-angle stratification are interpreted as hummocky cross-stratification that suggests deposition by successive storms that were strong or frequent enough to erode fair weather deposits (Dott and Bourgeois, 1982). Sandstone beds are clean because

wave action inhibits mud deposition and/or resuspends any slack-water deposits. Presence of bioturbation and association with the deformed sandstone of facies 18 suggests deposition in a wave/storm dominated delta front rather than a strandplain. Similar to facies 15 and 17 the event beds can represent deposition from hyperpycnal flows (Mulder et al., 2003). However, the deposits described here are different from the proximal delta front of hyperpycnal systems since they are typically 1–2 m thick, parallel laminated, coarse sandstone beds with, at times, inverse graded base and normal graded tops (Petter and Steel, 2006; Olariu et al., 2010).

The sedimentary succession in the distal core displays an alternation of fair-weather suites with *Cruziana* ichnofacies interrupted by storm events (Figs. 13, 17). The fair-weather assemblages are represented by thoroughly bioturbated muddy sandstones with *Thalassinoides*, *Asterosoma*, *Teichichnus*, *Paleophycus*, *Roselia* and *Planolites* (Fig. 13C). The main body of the storm deposit consists of low angle parallel to subparallel laminations in fine grained-sandstone interpreted as hummocky cross-stratification (Fig. 13 G, H). The sandstones are sharp-based, occasionally erosive with or without basal lags consisting of rip-up clasts (Fig. 17). The top of the beds are bioturbated by *Ophiomorpha* and *Paleophycus*. The intensity of burrowing is highly variable, depending on the severity and frequency of storms. Sedimentary structures and trace fossil associations indicate a transition of depositional environments from shelf below fair-weather base to wave-dominated delta front. Deltaic processes (proximity to a river outlet) and faunal environmental stresses are indicated by carbonaceous and/or mudstone drapes present in storm beds, soft sediment deformation structures and disseminated carbonaceous detritus. These shoreline deposits may represent the margins of strongly wave-influenced deltas, areas that morphologically would be included in the delta, but which lack active distributary channels and that receive most of their sediment by longshore drift (Ryer and Anderson, 2004). Facies association 5 is interpreted as a wave-storm dominated environment with minimal tidal influence based on the abundance of symmetrical ripples and hummocky cross-stratification. Some of the storm beds resemble hyperpycnal deposits (sharp to erosional bases, parallel to low angle laminations), but despite both being event beds the lack of inverse to normal grading throughout the succession suggests a wave-storm rather than river-flood dominance.

4.3.6. Facies association 6: transgressive shorefaces

4.3.6.1. Facies 20 — thoroughly bioturbated sandy mudstone (*Glossifungites* ichnofacies). The sandy mudstone is thoroughly bioturbated (BI 5–6) with *Planolites* and has organic matter disseminated throughout (Fig. 14A). Large *Thalassinoides* (up to 4 cm in diameter) are filled with very fine-grained sandstone. The sand fill of the *Thalassinoides* was brought down into the mudstone from the overlying unit (facies 1). Structureless burrow fill represent passive sedimentation. The fine-grained nature of the sediment, presence of organic matter, intensity of burrowing and relatively low diversity suggests deposition in a low energy environment such as a lagoon behind a barrier bar.

4.3.6.2. Facies 21 — moderately bioturbated fine-grained sandstone. The sandstone is structureless and moderately bioturbated (BI 4–5) with *Ophiomorpha* (Fig. 14B). This facies has a sharp, scoured contact with the sediments below (facies 20). The intensity of bioturbation increases toward the top as the sandstone becomes gradually finer grained. The erosional surface at the base of the sandstone is interpreted to be a wave ravinement surface created by wave erosion on the shoreface. The scoured base, fining-upward pattern, and increased bioturbation at the top of the sandstone reflect deposition on a drowning barrier bar as the water deepened during transgression, under wave-storm influence.

4.3.6.3. Facies 22 — thoroughly bioturbated very fine-grained sandstone. The sandstone is intensely bioturbated (BI 5–6) with *Ophiomorpha* and *Asterosoma* (Fig. 14C). All physical sedimentary structures are obliterated. The finer-grained nature and high intensity of bioturbation suggest deposition in a distal open marine setting under fair-weather conditions.

4.3.6.4. Facies 23 — thoroughly bioturbated fine-grained muddy sandstone with organic matter. Thoroughly bioturbated (BI 5–6) fine-grained muddy sandstone has organic matter disseminated throughout (Fig. 14D). The intense biogenic mottling with *Ophiomorpha*, *Asterosoma* and *Thalassinoides* trace fossils obscures any evidence of physical sedimentary structures. The intensity of burrowing and relatively low

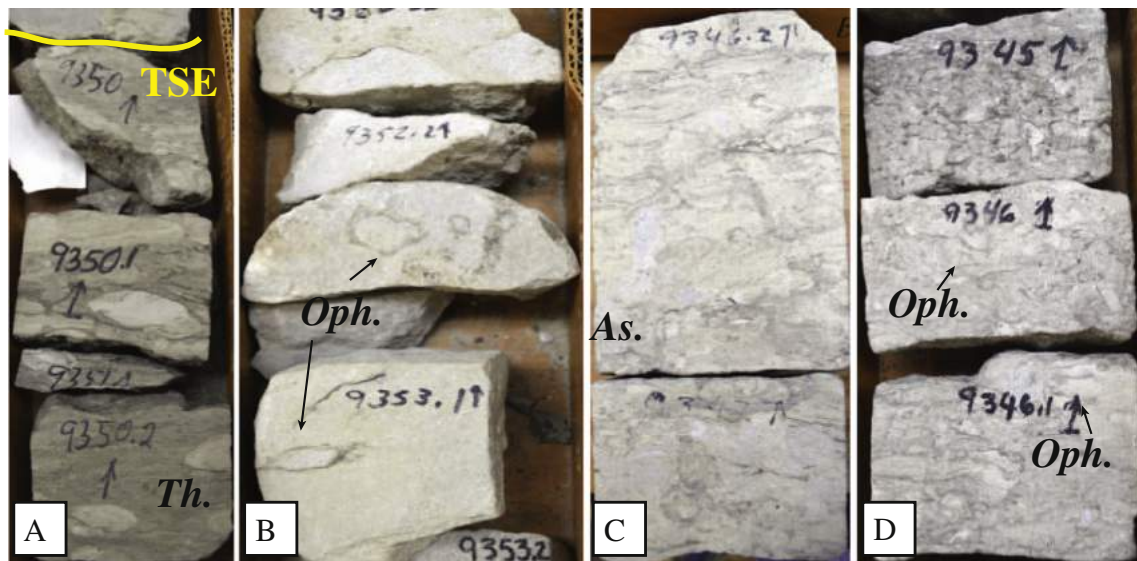
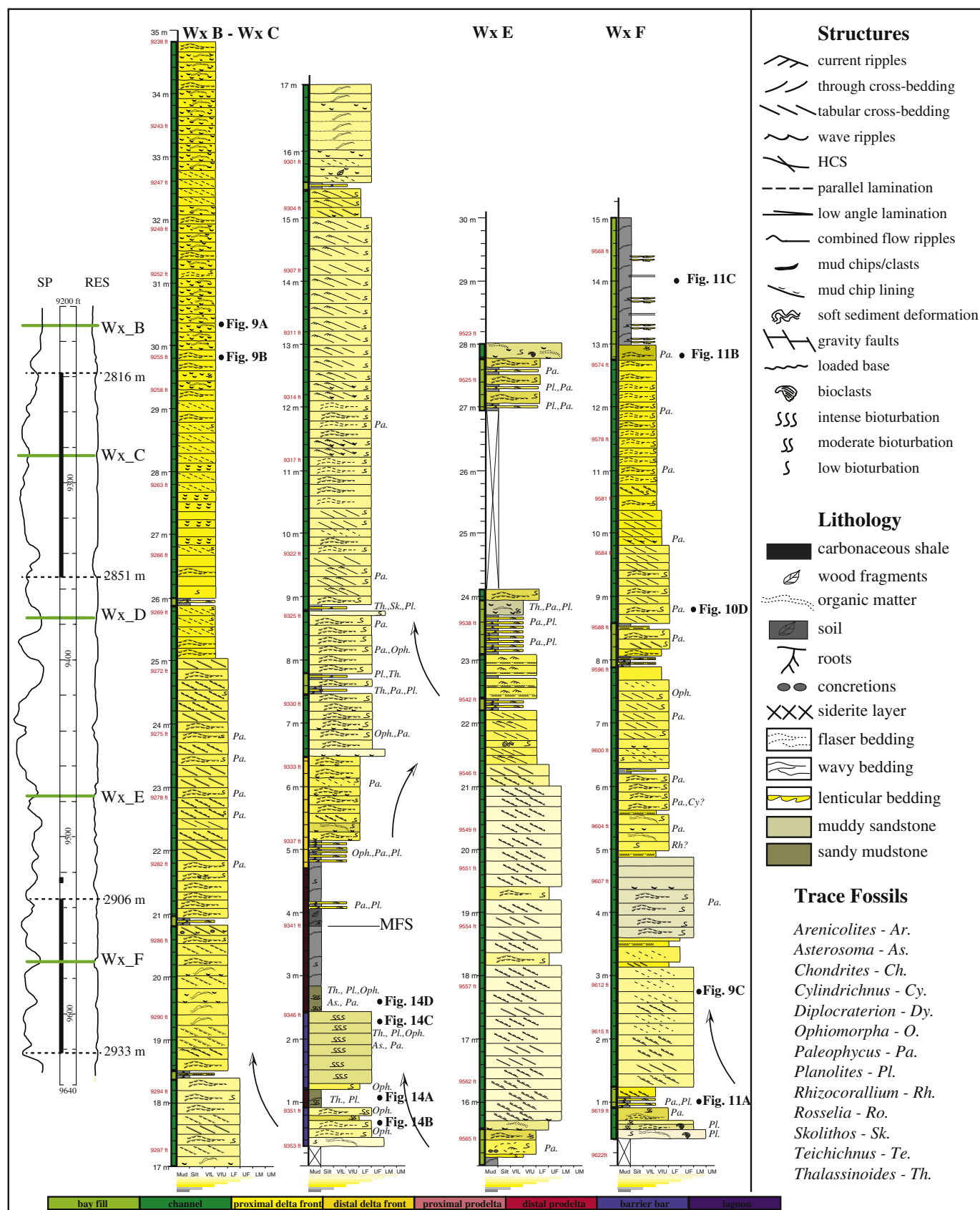


Fig. 14. Representative core samples showing characteristics of facies association 6 – transgressive wave-storm influenced shorefaces (each core sample is 9 cm wide; see well log in Fig. 4) A. *Glossifungites* ichnofacies – thoroughly bioturbated sandy mudstone with large *Thalassinoides* (up to 4 cm in diameter). B. moderately bioturbated fine grained-sandstone with *Ophiomorpha*. C. Thoroughly bioturbated very fine-grained sandstone with *Ophiomorpha* and *Asterosoma*. D. Thoroughly bioturbated fine-grained muddy sandstone.



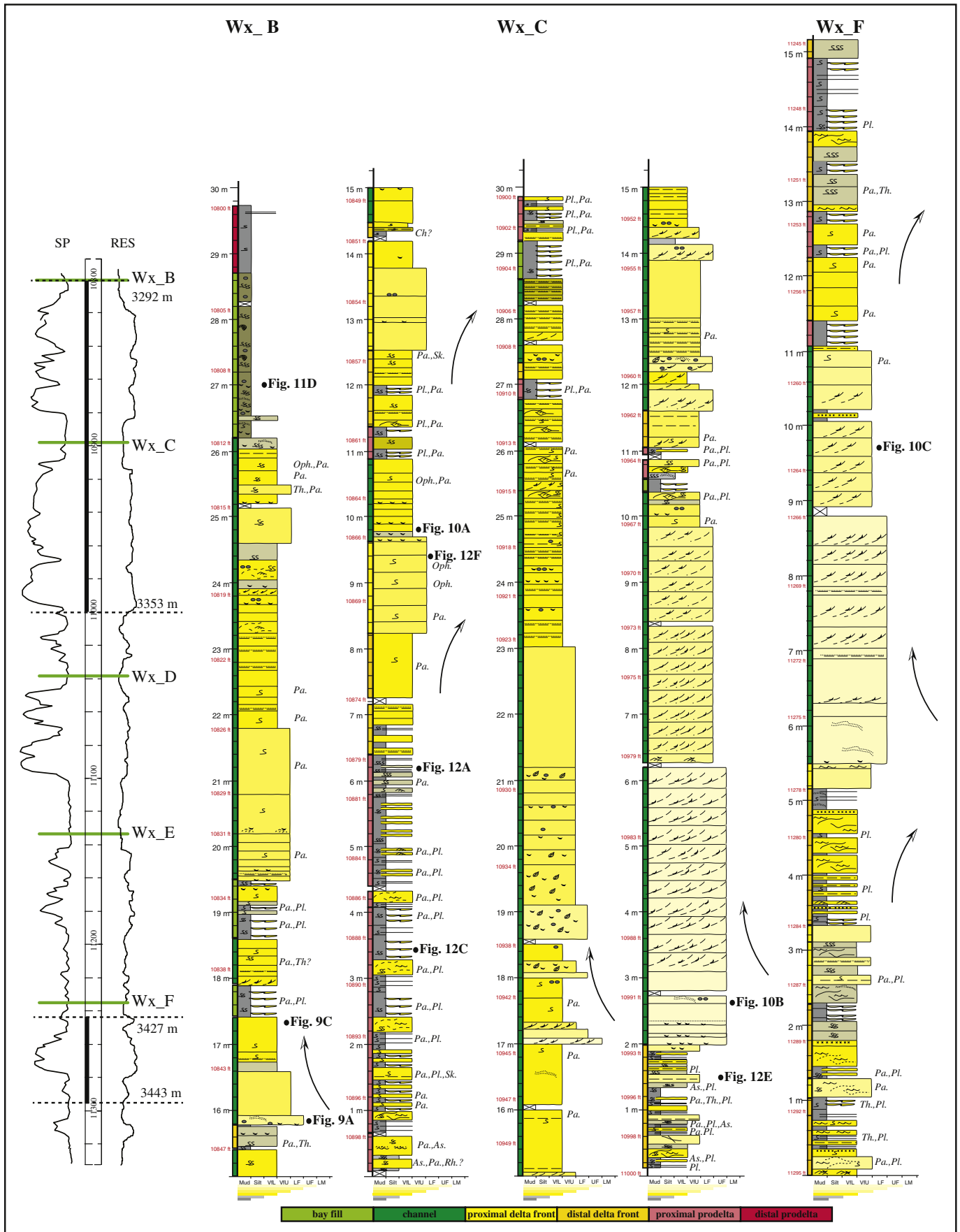


Fig. 16. Lithologic column for cored intervals (3292–3353 m; 3427.5–3443 m) and wire-line log type (SP and RES) in medial settings (see well log in Fig. 4). Upward-coarsening successions are interpreted to represent prodelta to delta front deposits either wave or tidally-influenced.

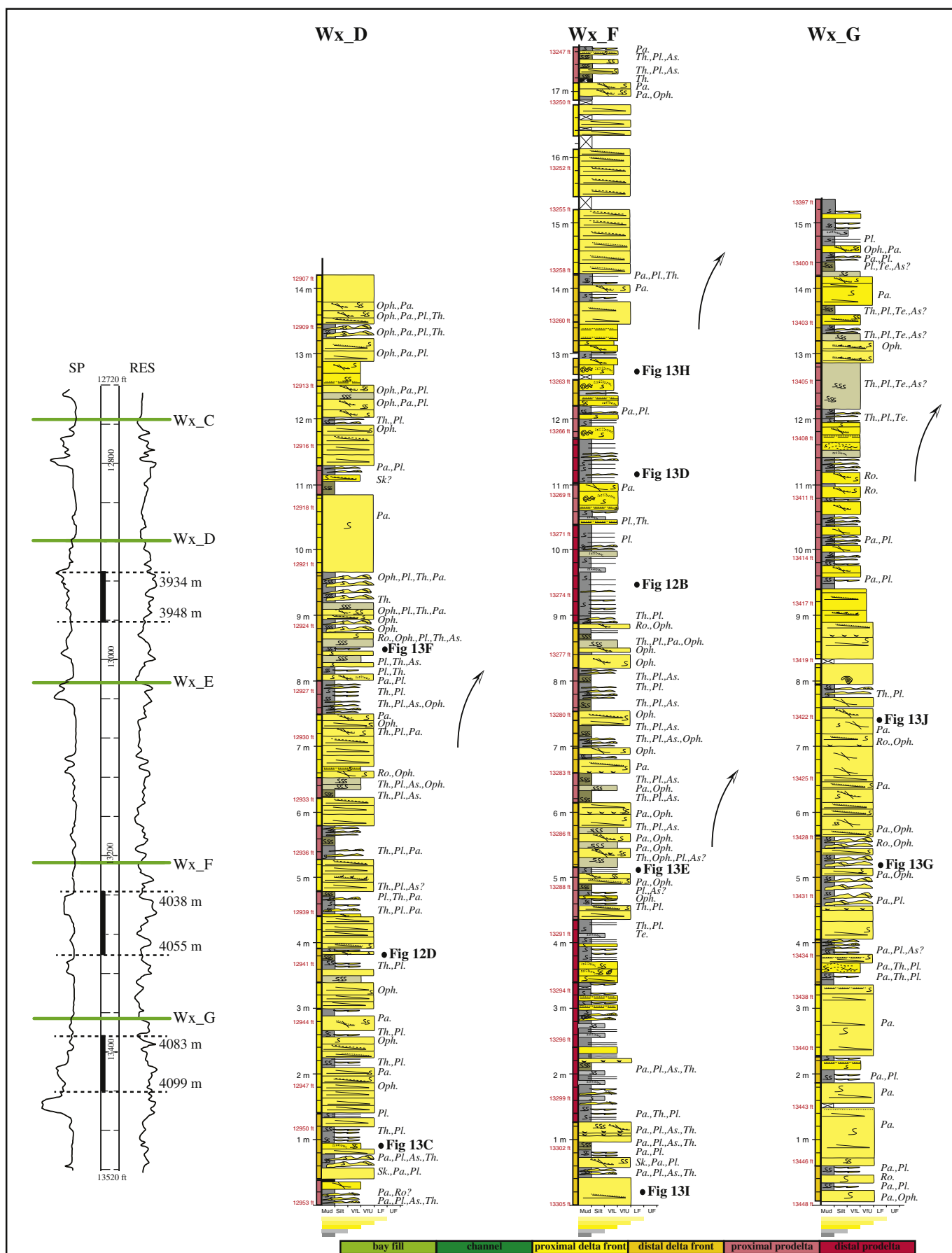


Fig. 17. Lithologic column for cored intervals (3934–3948 m; 4038–4055 m; 4083–4099 m) and wire-line log type (SP and RES) in distal settings (see well log in Fig. 4). Sedimentary structures and trace fossil associations indicate a transition of depositional environments from prodelta to wave-dominated delta front.

diversity suggests deposition in a restricted low energy environment such as a behind barrier bar lagoon.

The transgressive facies association (FA6) exhibits a fining-upward pattern. Erosion of shoreface deposits by wave action during transgression causes the shoreface to migrate landward (Cattaneo and Steel, 2002). The *Glossinifungites* ichnofacies records suspension feeding behavior and colonization of the exhumed surface after transgression (landward-stepping) of the shoreface (MacEachern et al., 1992). The erosional discontinuity at the base of the barrier bar sandstone (facies 21) is interpreted as a transgressive surface of erosion (TSE).

4.4. Shoreline deposits of the Lower Wilcox

The Lower Wilcox Guadalupe delta is characterized by an alternation of regressions and transgressions dominated by mixed (fluvial, wave and tide) shoreline processes (Figs. 15, 16, 17).

The proximal core (Fig. 15) records a vertical stacking of tidal distributary-channel deposits and adjacent tidal flats and lagoons (Figs. 10, 15). Lateral migration of channels has resulted in many of the sandstones being sharp based (Fig. 15). Channel deposits display gradational upward-fining successions from basal lags and sandy tabular cross-beds through heterolithic tidal flats into biologically homogenized mudstones (Fig. 15). Extensive burrowing suggests deposition under near normal marine conditions in tidal channels within the lower reaches of tide-influenced delta distributary similar to modern tide-influenced deltas such as Mahakam (Gastaldo et al., 1995; Salahuddin and Lambiase, 2013) and the Orinoco (Warne et al., 2002; Chen et al., 2015). Channels close to river mouths are subject to tidal influence especially during low river discharge periods (Dalrymple and Choi, 2007; Olariu et al., 2015).

In younger cycles upward-fining successions of fine-grained sandstone have abrupt, erosional bases with large sideritized mudstone or carbonaceous clasts and wood clasts/debris and no burrows (Figs. 9, 15). River derived stresses such as salinity fluctuations due to freshwater input and distributary-channel flood discharges laden with phytodetritus affect the viability of substrate habitation and are reflected in overall reduction in bioturbation intensity (MacEachern et al., 2005). As it is generally thought that an increase in salinity and bioturbation accompanies a decrease in suspended sediment concentration and tidal current speed in a seaward direction, this proximal section is interpreted to represent a shallowing-upward succession.

The medial core (Fig. 16) displays deposits of tidally- and wave-influenced deltas (Fig. 12). Tide-influenced deltas display a gradual transition from the prodelta mudstone to the delta front sandstone which indicates progradation of the delta. The prodelta is strongly heterolithic and displays flaser, wavy and lenticular bedding, indicating alternating traction sedimentation and suspension fallout (Bhattacharya and Walker, 1992; Willis, 2005; Willis et al., 1999). Delta-front deposits are characterized by an abundance of mud drapes mantling ripple and dune foresets, reflecting fluctuations (and reversals) in current velocities and mud fallout during slack water (Willis, 2005). Mud drapes in the sandstone are thought to accumulate from suspension during tidal slackwater, whereas sandstone layers are deposited during ebb and flood currents, similar to ancient and modern tide-influenced deltas such as Mahakam (Gastaldo et al., 1995; Salahuddin and Lambiase, 2013) and the Orinoco (Warne et al., 2002; Chen et al., 2014, 2015). Sparse burrowing with both dwelling and feeding structures (*Planolites* and *Paleophycus*) suggests either reduction of salinity (brackish water) or rapid sedimentation rates in the vicinity of the river mouth. Tidal channels cut through the mouth bar deposits into the upper part of the succession (Fig. 16). Tidal channels cutting delta tops and adjacent mud flats are reported to cap modern tide-dominated and tide-influenced deltas (e.g. Coleman and Wright, 1975; Allen et al., 1979; Salahuddin and Lambiase, 2013). Contemporaneous distributary channels eroding into

the tops of river delta-front successions are common, therefore the fluvial-dominated delta-front successions generally lack the abrupt, flat top characteristic of wave-dominated shoreline deposits (Ryer and Anderson, 2004). If the lateral migration of tidal distributaries is fast relative to delta progradation much of the delta front is replaced by distributary channel fill (e.g. Fly Delta; Dalrymple et al., 2003). There is a gradual upward-coarsening from heterolithic intervals of the prodelta to the sandier delta front deposits of the tidally-influenced deltas which can be recognized in wells by the serrated funnel-shaped log motif (Fig. 4C) similar to fluvial dominated deltas (Bhattacharya, 1988; Olariu et al., 2010). This lower delta front interval is overlain by an upward-fining succession of prograding deposits of lower and upper delta plain recognized in wells by a bell-shaped log motif (Fig. 4C).

Distributary-mouth bar deposits of wave-influenced delta fronts (Figs. 12, 16) lack the abundance of cross-stratification (Bhattacharya and Giosan, 2003) documented in distributary mouth-bar deposits of river-dominated deltaic lobes (Olariu and Bhattacharya, 2006). Wave-influenced delta fronts can be readily reworked by longshore currents with variable strengths and waves into hummocky cross-stratification (Bhattacharya and Giosan, 2003; Hampson and Storms, 2003). Relative proximity to river mouth is demonstrated by a mixture of current and wave processes, the presence of organic detritus and siderite cements similar to what was observed in the Ferron deltas in outcrop (Bhattacharya and Tye, 2004; Ryer and Anderson, 2004) and in modern deltas (Coleman and Wright, 1975; Galloway, 1975; Olariu, 2014). Physical sedimentary structures that indicate episodes of rapid sedimentation (event beds) include mudstone rip-up clasts, hummocky cross-stratification and structureless bedding. Scarce burrowing with *Ophiomorpha* near the top of the delta front sandstones is interpreted to reflect marine influence even in the proximal parts of the delta. Trace fossils are less abundant than in the shoreface deposits, but constitute the typical shoreface assemblage dominated by *Ophiomorpha* (Ryer and Anderson, 2004; MacEachern et al., 2005). The suppression of suspension feeding structures is thought to be associated with increased water turbidity and river-derived suspended sediment concentration (MacEachern et al., 2005). Wave-influenced deltaic successions commonly consist of thick, clean sandstone beds like the sandy shoreface sequences (Hampson and Storms, 2003), but include more mudstone interbeds and have, as a result, more gradational bases like the fluvial-dominated deltas (Ryer and Anderson, 2004). As a consequence, there is a gradual upward-coarsening from the prodelta (serrated funnel-shaped log motif) to the sandier delta front deposits (blocky log motif) (Fig. 4C).

The distal core exhibits an alternation of fair-weather suites with *Cruziana* ichnofacies (*Thalassinoides*, *Asterosoma*, *Teichichnus*, *Paleophycus*, *Rosselia* and *Planolites*) interrupted by decimeter-thick storm events with hummocky cross-stratification and common *Ophiomorpha* trace fossils (Figs. 13, 17). The deposits are interpreted as wave-dominated deltas with most of their sediment redistributed along shore by longshore drift. Although not directly influenced by rivers they are fed with sediment transported along shore from river mouths. Therefore alongshore away from the delta distributaries the deltaic lobes become wave-storm influenced shorelines. Proximity to a river outlet is indicated by carbonaceous and mudstone drapes present in storm beds, soft sediment deformation structures and disseminated carbonaceous detritus (MacEachern et al., 2005). Wilcox D and G are sandier and probably deposited in an axial/proximal setting (Fig. 18). Wilcox F displays a gradual upward-coarsening trend with a higher proportion of mudstone and heterolithic facies in the prodelta reflecting distal deposition laterally from the main axis where sedimentation rates were lower (Fig. 18). The heterolithic character of the distal facies indicates some tidal influence.

The dominance of storm processes reflects the position of the delta near the shelf edge as it is also suggested by the maximum regression shoreline position (R1) during Lower Wilcox Guadalupe Delta

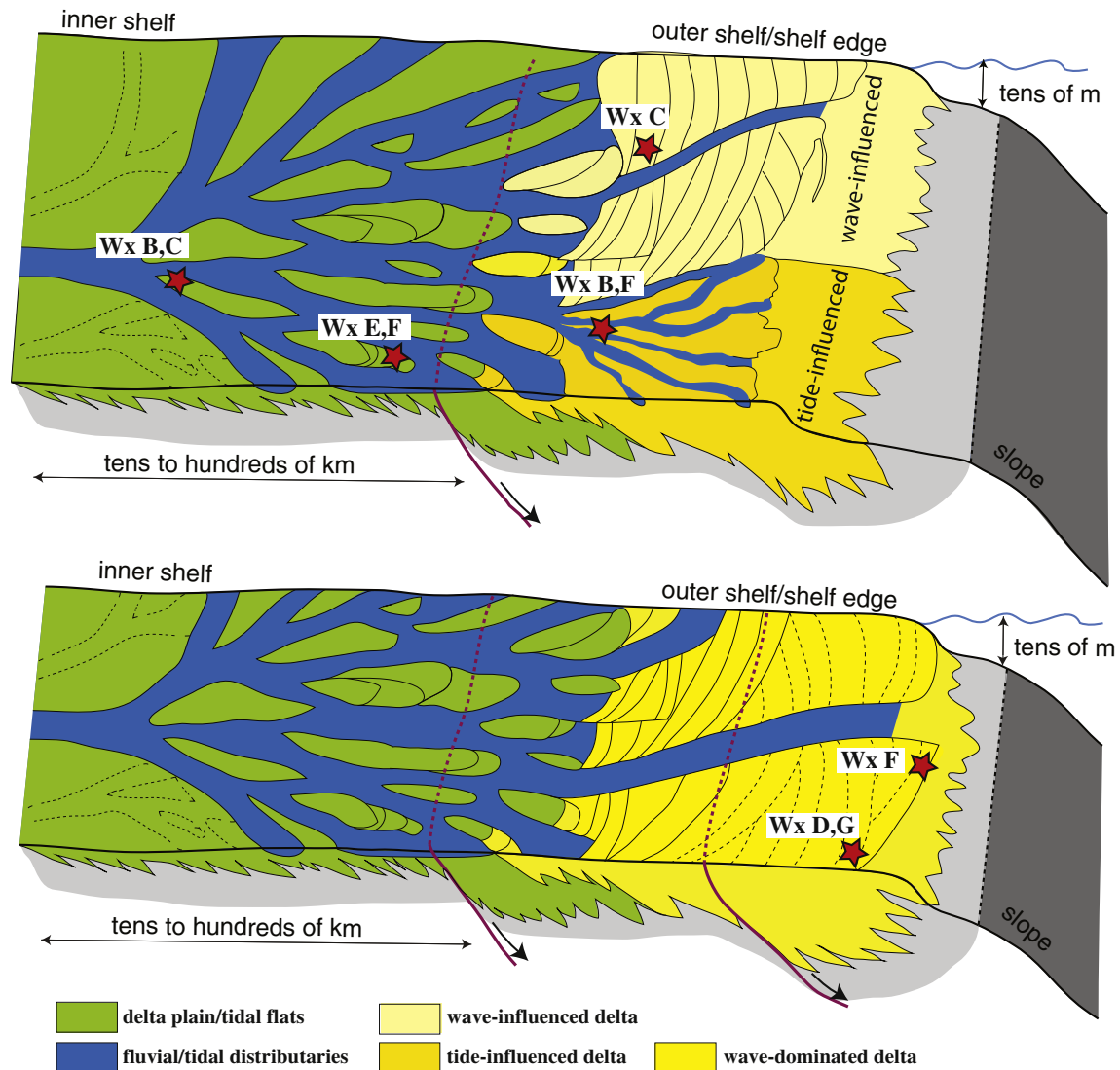


Fig. 18. Evolution of Guadalupe Wilcox deltas and process-regime change during cross-shelf transits from inner to outer shelf to shelf edge. River-dominated deltas, wave or tide-influenced on the inner shelf turn into wave-dominated deltas with some tide influence on the outer shelf because the wave energy increases relative to tidal or fluvial energy due to water depth and fetch and also because the sediment supply to the shoreline decreases due to delta topset aggradation (due to fault subsidence).

deposition on the paleogeography map (Fig. 2). Proximity to the shelf edge is also suggested by greatest fault displacement and section thickening in the rollover anticline (Figs. 6, 8). Soft sediment deformation suggests delta front instability possible linked to river floods or related to wave action that could have promoted delta front failure and wave-generated erosion (Hampson and Storms, 2003).

Thick (>100 m), upward-coarsening successions associated with large-scale growth faults result in short progradation distances (Olariu and Olariu, 2015) due to sediment trapping by faults. The delta expansion and dominance of wave-storm deposition have proven useful criteria in identifying shelf margin trends in other passive margin basins (e.g. Winker and Edwards, 1983; Suter and Berryhill, 1985; Porębski and Steel, 2003; Carvajal and Steel, 2009; Dixon et al., 2012).

5. Discussion

The Lower Wilcox Group in Texas has been interpreted at a large scale as a 3rd order clastic wedge of the Rockdale delta system (Fischer and McGowen, 1967; Xue and Galloway, 1993). Based on the dip-elongate pattern of the sandstone body in the subsurface, the Guadalupe B delta has been interpreted as fluvial-dominated (Fischer and

McGowen, 1967). This study shows that temporal and spatial variations in shoreline processes occur relatively fast over time intervals of less than a hundred thousand years. Process changes are linked with the evolution of growth faults that trigger changes over short distances (few kilometers) from one growth-faulted depocenter to the other (Fig. 7).

5.1. Process dominance of the Lower Wilcox shorelines and the main controls

Forth-order shoreline deposits of the Lower Wilcox have a wave-dominated character in distal settings, but locally fluvial and tidal processes can dominate (Figs. 15, 16, 17). Wave regime dominance with subordinate fluvial and tidal processes is documented in many ancient and modern regressive shoreline systems (Doust and Omatsola, 1989; Gastaldo et al., 1995; Hampson and Storms, 2003; Ryer and Anderson, 2004; Ainsworth et al., 2011; Bowman and Johnson, 2014; Olariu, 2014).

The main allogenic controls on deltaic sedimentation are the physiology of the receiving basin, sediment supply, eustatic sea level variations and tectonics (Galloway, 1989; Orton and Reading, 1993). Short term variability in deltaic processes can be explained by the

relative interplay of river discharge, wave energy and tidal range (Orton and Reading, 1993; Ainsworth et al., 2011; Olariu, 2014). Local high fault-controlled subsidence rates influence sediment pathways and the distribution of facies and depositional environments. Strong river discharge provides a great amount of sediment at the river mouth loading and deforming the delta front (Bhattacharya and Davies, 2004). As sediments move basinward across normal faults subsidence plays an important role by creating increased accommodation which locally slows deltaic progradation (Olariu and Olariu, 2015) and concentrates sediments in elongate belts along the shelf margin (Olariu et al., 2013; Bowman and Johnson, 2014). Since accommodation is continuously created and filled, the maximum regression point of the shoreline remains roughly in the same position over time giving more time for wave-reworking per unit sediment (Olariu et al., 2013; Olariu and Olariu, 2015). A stronger wave regime is favored on the outer shelf due to unrestricted fetch and water depth (Porebski and Steel, 2003). In wave-dominated deltas the sediment delivered to the distributary-mouth bar is carried away by longshore transport (Coleman and Wright, 1975; Coleman, 1976) decreasing the shoreline 'bulge' (Nienhuis et al., 2015) and commonly forming asymmetrical sand-mud distribution in the delta front (Bhattacharya and Giosan, 2003). Compared to fluvial-dominated deltas, the progradation rate of wave-dominated deltas is retarded (Bhattacharya and Tye, 2004) therefore deltas stay in an outer shelf position longer and are reworked by waves longer (Olariu and Olariu, 2015). A balance between the rate of accommodation creation and sediment supply results in an aggradational stacking pattern (Mitchum and Van Wagoner, 1991). Similar to lower Wilcox deltaic deposition, increased subsidence along growth faults in the Champion (Saller and Blake, 2012), Niger (Jermannaud et al., 2010; Rouby et al., 2011) and Orinoco deltas (Bowman and Johnson, 2014) slowed basinward progradation of deltaic complexes producing significant aggradation in the growth-faulted depocenters.

Overall in all three studied Lower Wilcox cores and in the well log data base changes have been noticed in the dominant depositional processes acting at the shoreline through time and space. There is a transition from delta plains to wave- and tide-influenced deltas to wave-dominated deltas (Figs. 15, 16, 17, 18) which is commonly observed in many modern and ancient deltas (Gastaldo et al., 1995; Warne et al., 2002; Salahuddin and Lambiase, 2013; Vakarelov and Ainsworth, 2013; Chen et al., 2014; Olariu, 2014). However, this transition in the lower Wilcox deltas is thought to occur because of the interplay between the spatial distribution of sediment supply and creation of accommodation due to fault subsidence in the downthrown compartment. Thus, the progradation rate of wave-dominated deltas is retarded; hence, deltas stay at the shelf edge and are reworked by waves for longer periods of time. Consequently, the primary reason for enhanced wave dominance is a slow progradation rate (less sediment supplied to the same shorezone width per unit time), or alternatively the partitioning of sediments over large areas (increasing the shorezone width along strike), giving less sediment supplied in the shorezone per unit time (Olariu and Olariu, 2015). Growth faults act as an additional control on the outer-shelf, increasing the probability of wave-dominated deltaic sedimentation in the growth-faulted compartments.

Autocyclic changes within the deltaic system also lead to considerable spatial and temporal facies variability in many modern and ancient deltas (Ainsworth et al., 2011; Olariu, 2014). The dominant depositional process can change down depositional dip as the delta progrades across the shelf and into slightly deeper water, or laterally because of shifting fluvial discharge or because of oceanographic differences between distributaries (Olariu, 2014).

5.2. Reservoir considerations

As the lower Wilcox Guadalupe deltas crossed the shelf and reached the shelf edge the delta style changed from wave- and tidally-

influenced to wave-dominated deltas. The dominant sedimentary process influences the delta architecture and reservoir quality. River and tide deltas are shore perpendicular and have a lobate elongate geometry (Coleman and Wright, 1975), whereas wave-dominated deltas are commonly shore parallel with a strike elongate geometry (Bhattacharya and Giosan, 2003). The delta architecture is more complicated when mixed processes (wave, tide, fluvial) occur at the shoreline (Gani and Bhattacharya, 2007). It is shown in many studies that the reservoir geometry, size and properties (internal facies pattern) are significantly different for fluvial-dominated (Enge and Howell, 2010; Olariu et al., 2010), shoreface and wave-dominated deltas (Galloway, 1986; Larue and Legarre, 2004; Sech et al., 2009) and tide-dominated deltas (Allen and Mercier, 1994; Dreyer et al., 2005). However, within a wave-dominated deltaic succession (lower Wilcox in distal growth-faulted depocenters) the clean sandy storm beds make attractive hydrocarbon reservoirs. The vertical permeability is good within the stacked sandstone beds (Galloway, 1986). The prodelta mud might baffle vertical flow in places but, the overall lateral continuity of the clean sandstone beds makes wave-dominated deltas prolific reservoirs.

The Wilcox stratigraphic section has long been recognized as an important petroleum resource in Southeast Texas, producing primarily gas from fluvial, deltaic and shallow marine sandstone reservoirs. The total estimated ultimate recovery for the onshore Wilcox is about 680 km³ of gas (Dave Meyer et al., 2005). Oil and gas accumulation in the lower Wilcox is closely controlled by distribution of specific deltas of the Rockdale Delta System (Fischer and McGowen, 1967) with principal reservoirs being the delta front sands and proximal deltaic facies (distributary-mouth bars and channels). The lower Wilcox in De Witt County is especially attractive because it has produced 1.5 km³ of gas and it is actively producing (Bilingsley, 1982).

6. Conclusions

Lower Wilcox shelf margin deltas are linked to active growth fault systems that catch most of the sandstone in outer shelf to upper slope expanded sections. Subsiding growth-faulted depocenters efficiently trap deltaic sediment and slow shoreline progradation. In the study area, third-order Guadalupe B Delta (made up of 10 fourth-order cycles) is a mixed depositional system. Shoreline process dominance changes during regression from wave and tide-influenced to a wave-dominated regime. Sandstone maps show that deltas thickened and storm-wave influence became dominant closer to the shelf edge. Increased likelihood of wave-process dominance in the outer shelf environments is explained by reduced progradation rates due to increased accommodation due to fault-driven subsidence in the vicinity of the shelf edge which reduces deltaic progradation, favoring increased wave reworking and delta aggradation. The local increased subsidence with pervasive wave reworking generates attractive (thick and relatively clean) shoreline associated reservoirs with a strike-elongated geometry.

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